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Sewage Research

RESEARCH IN SEWAGE CHEMISTRY, SEWAGE TREATMENT AND STREAM POLLUTION

A CRITICAL REVIEW OF THE LITERATURE OF 1937

By Gail P. Edwards, Charles A. Emerson, Jr., Harry A. Faber, H. F. Gray, H. Heukelekian, W. Rudolfs, Harold W. Streeter and Earle B. Phelps, *Chairman*

Committee on Research, Federation of Sewage Works Associations

(1) Chemistry and Biology

In view of the increasing rate of expenditure of money in construction and operation of sewage treatment works, the amount of fundamental research being conducted and reported appears unduly limited. Several important individual studies have been presented which deal with the mechanisms, reactions and theories involved, but our knowledge is as yet insufficient to be built into general theories. Some general hypotheses which have been accepted need re-examination. Nevertheless, the past year has shown some interesting developments, both in theoretical considerations and in practice, and has given us new knowledge of the complex phenomena taking place in polluted streams and usually grouped together under the term "self-purification."

Biological.—Studies on the effect of temperature and exposure to light on the decomposition of sewage in river water by Butcher, Longwell, and Pentelow show that increased temperature causes a rapid increase in ammonia which is converted to nitrites and nitrates. The decomposition and self purification processes take place in three stages: (*a*) development of bacteria and decomposition of substances with the production of ammonia, (*b*) reduction in numbers of bacteria and increase in numbers of protozoa and the production of large quantities of nitrite with an increase in the total quantity of nitrogen, and (*c*) production of nitrate and the formation generally of simple products of oxidation of organic matter. The stages of decomposition overlap to some extent. Under conditions of intermittent exposure to light the rate of self-purification of a mixture of river water and sewage is greater than under continuous exposure to light or in darkness throughout. During the process the numbers of bacteria are never constant, but are either increasing or decreasing, but on exposure to light they remain constant.

Biological theories of natural and artificial sewage purification have led to the conclusion that the principal role of protozoa in polluted water is to keep bacteria in check. Under these conditions the bacteria are stimulated to multiply more rapidly and are thereby more effective

in purification. On the basis of extensive studies Viehl believes that the role played by the bacteria and protozoa in streams and activated sludge is as follows: Oxidation of soluble material is caused by bacteria; protozoa have no practical influence in this activity, but flocculation and adsorption of colloids is a function associated with protozoa, especially ciliates. These organisms regenerate sludge particles, restore adsorptive power and thereby speed up adsorption processes. When protozoa are incapable of handling the process bacteria must take their place. Bacteria cannot take up suspended matter the same as ciliate protozoa, they must employ enzyme action. This requires time and consequently colloids are removed at a slower rate than by adsorption. The absence of protozoa, therefore, usually results in a more turbid effluent from activated sludge plants and a slower clarification of polluted streams. The influence of protozoa in the self-purification of stagnant sewage is believed by Liebman to be unimportant. As a matter of fact, he thinks that protozoa are not concerned at all in the stabilization of stale sewage, because the maximum concentration of hydrogen sulfide which the ciliates can endure amounts to only 18 p.p.m. From our point of view this is a rather large amount of hydrogen sulfide. The same writer states that *Colpidium colpoda* can live symbiotically with chlorobacteria in oxygen-free water.

Results obtained by the Water Pollution Research Board lead to the conclusion that the greater part, if not all, of the oxidation of sewage by air is dependent on the presence of certain enzymes in sewage or sludge. The most potent source of enzymic activity appears to be bacterial cells, partly because bacteria are usually so much more numerous than other micro-organisms, such as protozoa, and partly because enzymic activity of the bacterial cell appears to be greater than that of protozoa. It was found that many of the dead bacteria present in the sludge retain a degree of oxidizing activity and, because of their predominating numbers (from 100 to 1,000 times more than live bacteria), play an important part in the oxidation of sewage.

The continued activity of the sludge, even when saturated with sewage, suggests that some of the soluble constituents may be oxidized in solution and some after adsorption on the surface of the sludge. In this respect the studies of Heukelekian are illuminating. He found that mechanical mixing of sewage, which is known to enhance clarification, results in higher bacterial numbers. Saturating activated sludge with sewage colloids resulted in impaired clarification, while saturation of sludge with kaolin did not affect its clarifying power for sewage. Similarly, butyric acid treatment of activated sludge did not affect its clarifying power. Increasing the ammonia content of the sludge or that of the sewage did not affect the clarifying power of sludge for sewage. He concluded that clarification is a complex phenomenon brought about by a number of factors. When the CO_2 production was measured over short intervals during the aeration of activated sludge and sewage mixtures, the highest rate was found to occur during the initial period. These findings emphasize the importance of oxidation

during the clarification stage and the fact that biochemical oxidation systems in the activated sludge have the potentiality, with proper stimulation in the presence of food and air, to react rapidly without any lag.

In studies on biochemical oxidation of sludges developed by pure cultures of bacteria isolated from activated sludge, Butterfield, Ruchhoft and McNamee showed that the addition of fresh nutrient substrate to these pure culture activated sludges caused greatly increased oxygen utilization under aeration. They concluded that the reactions are of the same general type but that the velocity constants are much greater than in normal biological oxidation. No doubt there are considerable groups of such bacteria present in the activated sludge, capable of such action.

Experience with activated sludge has shown that if sludge is overworked it becomes much less effective as a purifying agent. Laboratory experiments seem to support the view that this is mainly due to a super-saturation of sludge with certain constituents of sewage, and that when this condition exists the addition of a further quantity of sewage cannot lead to any increased activity. This was shown previously by Heukelekian when a normal activated sludge was overloaded. A sludge can consistently take care of a definite quantity of raw suspended solids, but an excess is not readily oxidized. This is confirmed by the Water Pollution Research Board who find that sludge saturated with sewage will not oxidize further additions of sewage until the concentration of the substrate in the saturated sludge has been considerably reduced by further aeration. The saturated sludge, however, has a much greater rate of adsorption of oxygen than the initial sludge from which it is prepared.

Dienert believes that symbiosis among the bacteria is necessary for vigorous action; oxidation, reduction and clarification may be accelerated by mixing different species of bacteria, and insofar as the zoogleal mass can be broken up, purer strains of bacteria can be obtained. It is the development of zoogleal-forming bacteria, however, which forms the activated sludge proper. Only when the zooglea develops are fine suspended particles agglutinated in the mass. Agitation will return larger flocs to the liquid but not fine particles (provided agitation is not so severe that the flocs are broken), while insufficient agitation leaves some fine particles in suspension. It is visualized that the same phenomenon occurs in trickling filters. Dienert claims that the multiplication of these organisms is very slow when organic matter is too concentrated in the liquor and that this organic matter is then transformed and degraded by proteolytic bacteria. It would seem to be logical that all organic matter must be hydrolyzed before it can be utilized by bacterial action and stabilized.

For several years Lackey has been collecting samples of plankton from stagnant and flowing waters and sewage treatment devices. Of 348 species of organisms 57 are of common occurrence. Of 98 species found in Imhoff tanks, 88 occurred in grossly polluted streams. Al-

though it is surmized that protozoa play an important rôle in self-purification of streams, and the stabilization of sewage in trickling filters and activated sludge, the information is scant beyond enumeration of species.

The formation of elemental sulfur in sludge digestion, which has been observed in laboratory experimentation to the extent that a yellow coat of sulfur was formed on the walls of bottles, is of practical as well as theoretical interest. The odors produced during sludge digestion and in sludge banks in rivers are due mainly to hydrogen sulfide. The formation of such elemental sulfur under anaerobic conditions has been questioned and studies throwing light upon this phenomenon are of interest. The utilization of sulfur compounds by purple and green sulfur bacteria and the utilization of organic compounds is described by Van Niel who shows that the metabolism of these organisms is a truly photosynthetic process, which can be considered as one of a number of possible photosynthetic reactions of the general type:

$$CO_2 + 2\ H_2A = CH_2O + H_2O + 2\ A.$$

The green sulfur bacteria dehydrogenate the hydrogen sulfide to sulfur and under favorable conditions the purple sulfur bacteria dehydrogenate hydrogen sulfide, sulfite and thiosulfate completely to sulfur. In the absence of oxidizable sulfur compounds the purple sulfur bacteria can develop in the presence of organic compounds under completely anaerobic conditions. No growth has been obtained in the presence of oxygen.

Colloids.—Studies on colloids reported upon in our 1937 review have been continued by the Water Pollution Research Board. The earlier experiments showed the effects of bubbles of air, oxygen, hydrogen and nitrogen in flocculating dispersed materials. Further experiments have indicated that an appreciable proportion of organic matter in sterilized sewage can be coagulated at 25° C. by bubbling gases through the liquid, but the amount is less than with unsterilized sewage. Some simple experiments have also been conducted on the effects of addition of sewage and proteins on coagulation of clay suspensions by means of electrolytes. Mills has summarized the work done during 1930–36 on suspensions, colloids, dispersion and solutions in an effort to connect the different phases of sewage treatment. Although no new work is presented the attempt to bring together the part played by dispersed and colloidal matter in sedimentation, bio-flocculation, activated sludge, trickling filters and sludge digestion is interesting reading and gives food for thought. The fact remains that insufficient data are available on the amounts of dispersed and colloidal matter in sewage and on the factors affecting these amounts, to give a proper understanding of practical methods of treatment for varying local conditions. Further study on the mechanisms operative in present treatment processes is necessary to increase the efficiency of the present methods and evolve new or greatly improved methods. Experiments by Rudolfs and Gehm are discussed in Section 4.

Methods.—Several investigators have called attention to the fact that under certain conditions the B.O.D. determination is influenced by dilution water, especially the mineral content of such dilution water. Lea and Nichols supplemented the dilution water with various salts and concluded that the B.O.D. of certain wastes is abnormally low if the wastes are deficient in nitrogen and phosphorus. Addition of these compounds to the dilution water, or admixture with sewage, results in normal B.O.D. values. Studies on oxygen demand of polluted waters by Burtle included moist combustion, B.O.D. by the dilution method, oxygen consumed and direct absorption tests. He found that the oxygen consumed, by the permanganate test, gives only partial and erratic results. The dilution B.O.D. is distinctly an empirical determination, and measures only the amount of oxygen taken up from a dilution water of a certain type in a given time under particular conditions. Values obtained under such conditions have meaning only as long as the conditions remain fixed. The values can be reproduced in a direct absorption apparatus although the results are just as empirical. Moist combustions have been made from time to time and it is believed that they give promise of becoming useful in sewage analysis. Values can be reproduced and show a certain consistency when compared with results from other oxygen demand tests. There is not sufficient information available to determine whether the values obtained in moist combustion tests are absolute.

The author finds little correlation between his moist combustion determination of carbon, and the B.O.D. values. This would have been more obvious had he used a wider range of materials, including pure carbon. His conclusions ignore the fact that stream conditions involve biochemical reactions, which are measurable only in terms of available food energy. This fact lies at the bottom of the usefulness of the B.O.D. test.

A modification of the chlorine demand test and the orthotolidine test for residual chlorine in sewage was made by Symons. See Section 5. The fact that oxygen demand can be treated mathematically, no matter whether it deals with stream pollution or sludge digestion, indicates that the complex processes involving biological, chemical and physical factors repeat themselves in such a manner that "standard demand curves" can be plotted. Velz, using the integrated deoxygenation liabilities and reoxygenation assets and the factors influencing the rates of change in each by coefficients originally developed by Streeter and Phelps, has produced an ingenious diagram whereby the complex diffusion equation can be solved graphically for any given set of conditions. By plotting the logarithms of oxygen demand of organic materials, expressed as percentages of the initial total demand, against time for rates at different temperatures a group of standard demand curves is obtained, the lines of which can be utilized to estimate the relative effects of different waste contributing communities upon a stream.

Sludge Digestion.—Attention was called in last year's review to the

dearth of information regarding the mechanism of and organisms responsible for sludge digestion. It was stated that the standard bacteriological technique had been only partially successful in furnishing this much needed information. Two articles by Barker are of considerable interest. The first of these deals with the biochemistry of methane fermentation. Materials such as protein, celluloses, hydroxy acids, etc., cannot serve as food for methane organisms. They are first attacked by the more common saprophytic anaerobes, which produce lower acids and alcohols. These products are utilized by the methane bacteria and no other organisms are known to attack them under anaerobic conditions. The only reduction product formed by the utilization of these acids and alcohols by the methane organism is methane. The author generalizes Sohngen's earlier demonstration of the reduction of CO_2 with gaseous hydrogen by methane bacteria to the mechanism of methane fermentation of organic substrates. The generalization states that methane is derived not from the reduction of a part of the substrate molecule but from the reduction of carbon dioxide and is effected by all compounds which are capable of acting as hydrogen donators according to the following equation:

$$4\ H_2A + CO_2 = 4\ A + CH_4 + 2\ H_2O.$$

H_2A representing any compound which can be activated by the methane bacteria to act as H donator for the reduction of CO_2.

The fermentation of ethyl alcohol was found to proceed by hydrogenation quantitatively to the acetic acid stage and at the same time there was consumed a quantity of carbon dioxide equivalent to the methane formed. Sodium bicarbonate in the medium supplied the necessary CO_2 for the reaction initially until sufficient acetic acid was produced to produce CO_2 from $CaCO_3$. There are two stages in the fermentation of ethyl alcohol, first the production of acetic acid and second the decomposition of the acid. During the first stage CO_2 is actually consumed according to the following reaction:

$$2\ C_2H_5OH + 2\ H_2O = CO_2 + 2\ CH_3COOH + CH_4 + 2\ H_2O.$$

The $CaCO_3$ added to the medium to neutralize the acidity produced will in turn react with the acid to produce a new molecule of CO_2 ready for further reduction. No organisms except the methane bacteria are known to utilize alcohols under anaerobic conditions. In the early stages of alcohol fermentation the CO_2 content of the gas is about 15 per cent and CH_4 85 per cent. As the fermentation proceeds CO_2 decreases gradually to 3 per cent and CH_4 increases to 97 per cent. Butyl alcohol similarly is first dehydrogenated to butyric acid with simultaneous uptake of carbon dioxide and production of CH_4 and the butyric acid is then further dehydrogenated to acetic acid with the production of CH_4.

The acetic acid produced from the dehydrogenation of ethyl and butyl alcohols or the acetic acid added to the medium directly is fermented further by the reduction of CO_2. The disappearance of CO_2

by reduction is in this instance obscured by a simultaneous production of carbon dioxide as a result of the complete dehydrogenation of the acetic acid.

Applying these findings to mixed cultures as in sludge digestion, other types of fermentation take place simultaneously with methane fermentation. Such fermentations may predominate during the early period of digestion giving a higher percentage of CO_2. When the methane fermentation becomes established the CO_2 produced by the other organisms may be hydrogenated by the methane bacteria resulting in lower CO_2 and higher CH_4 as digestion proceeds. In the presence of a mixed flora, acting on a variety of substrates, the CO_2 necessary for the methane fermentation to proceed does not become a limiting factor. The fact that in sludge digestion maximum acid production is coincident with maximum CO_2 values is not opposed to Barker's observations because high CO_2 values during the early periods of digestion may be derived from other than methane fermentations.

A further indirect confirmation of these views lies in the general absence of H in the gases during sludge digestion. As long as there is an excess of CO_2 the hydrogen liberated from the dehydrogenation of organic substrates will be utilized to hydrogenate or reduce the CO_2. The occasional occurrence of hydrogen in small amounts in the gas from sludge digestion may be accounted for by the preponderance of non-methane fermentations caused by abnormal conditions of digestion and certain materials present in the solids.

Barker also attempted to isolate the organisms responsible for the fermentation. With the knowledge of the essential physiological character of the organisms and biochemistry of the fermentation it was comparatively simple to devise methods of cultivating the organisms. One of their characteristics is a sensitivity to O_2 greater than that of most anaerobic bacteria. To insure absolute anaerobiosis H_2S in the form of Na_2S was added to the medium after boiling and cooling. The importance of maintaining strict anaerobic conditions increases with the number of transfers and by elimination of the other saprophytic organisms which in the initial transfer render the medium anaerobic by their respiration and activity.

Initial impure transfers may produce sufficient CO_2 for the metabolism of methane bacteria but as the purity of the culture increases with successive transfers it becomes essential to supply a source of CO_2. The nitrogen requirement of the methane bacteria is satisfied with ammonia. The choice of organic substrate for carbon metabolism can be satisfied by a number of compounds depending on the type of methane organism that is desired. Only simple organic compounds should be selected which are not fermented under anaerobic conditions by the more common saprophytic bacteria. Calcium acetate and butyrate and ethyl alcohol were used by the author for the enrichment of the different methane bacteria.

A characteristic of the methane bacteria is their very low rate of development due to the low energy yield from the fermentation process.

Initial inoculations from soil, mud, etc. require two weeks at 35° C. for development. As the culture becomes purified by successive transfers the time required for the development of the organisms increases. The size of the inoculum also affects the time required. After the enrichment process has been carried on in liquid media by successive transfers the organism can be grown and isolated from agar shake tubes. The composition of this medium is the same as the liquid medium solidified by agar. The development of methane bacteria in these shake cultures is indicated by the production of gas which causes a splitting of the agar and a rising of the paraffin plug and the formation of easily distinguishable colonies.

Barker distinguishes four types of non-spore forming non-motile bacteria.

1. *Microsarcina* fermenting acetic acid and also probably butyric acid but not ethyl alcohol. Large spherical cells grouped to form cubical sarcina packets.

2. *Methanococcus* present in calcium acetate cultures and fermenting it more vigorously than the sarcina. It is also present in butyric acid cultures and in the later stages of fermentation of ethyl and butyl alcohols. Small spherical cells occurring singly, in small groups or in larger aggregates.

3. *Methane Bacterium.*—One of these rod shaped organisms ferments acetic and butyric acids but not ethyl alcohol while the other ferments ethyl alcohol and not the acetic acid.

None of these organisms were obtained in pure cultures but only in highly purified state.

The value of this investigation lies in the fact that by the use of the special media and precautions suggested by the author an estimate of the number of methane bacteria in sludges may be made for the first time. It is apparent from the characteristics of these organisms that they are not included in any of the counts made by the standard bacteriological technique. If a method can be developed for the estimation of their numbers it will be of importance from the standpoint of determining the influence of certain environmental conditions in sludge digestion.

Temperature.—Fair and Moore have published the results of experiments on the effect of temperature on the time and rate of digestion. The temperatures studied were 59, 68, 77, 86, 95, 104, 113, 122 and 140° F. The sludges were acclimatized to the various temperatures by a preparatory series of digestions. The time of digestion for this preliminary series varied from 282 days at 59° F. to 36 days at 95° F. Finally fresh sludges seeded with these acclimatized sludges were digested at the corresponding temperatures. Relative times of digestion ranged from 67 days at 59° F. to 9 days at 140° F., taking 90 per cent of ultimate gas production at 59° F. as the end point. These times, plotted against temperatures, fall into two distinct curves, quite similar in form to those previously found by the authors in compiling results from various sources, indicating a mesophylic optimum tem-

perature of between 95° and 100° F. and that for thermophilic digestion, at 125°–130° F.

(2) Activated Sludge

During the past year, our knowledge of activated sludge has been increased, not only by research in the fundamental principles of the process but also by improvements in operation and economical design.

Mechanism of the Activated Sludge Process.—Although it has generally been believed that higher organisms such as protozoa are necessary for carrying on the activated sludge process, Butterfield, Ruchhoft and McNamee, have isolated bacteria from normal activated sludge which have reproduced similar sludge in pure culture. (See Section 1.) The authors believe that one of the most important characteristics of this type of organism, in addition to its oxidizing ability, is the capacity to form in a liquid medium a massed floc or colony which holds together during the agitation of aeration.

The results of work by Dienert and of Viehl bearing upon this subject have been referred to in Section 1.

Freese used air and nitrogen in parallel experiments to agitate mixed liquor and obtained almost equally satisfactory purification with each. His results indicated that a large part of the oxygenation occurs as the bubbles break the surface of the mixed liquor. This conclusion is at variance with Heukelekian's results (see preceding Section), and with results obtained at Lawrence in 1919. Perhaps the difference in results may be explained by difference in procedure.

Zigerli reports that finely divided asbestos added to an aeration tank acts as a contact material to which the biological organisms adhere. In this "Z" process of sewage treatment, the raw sewage is settled for 30 minutes to remove about 75 per cent of the settleable solids, then mixed with the asbestos fibre and aerated for an hour. The asbestos is removed by settling and returned to the aeration tank. The excess sludge, which has a moisture content of 96.4 per cent, is only about 0.1 per cent of the daily sewage flow as compared with 1 to 3 per cent for normal activated sludge. Experimental results indicated reductions, based on the settled sewage, of 86 per cent in suspended solids, 76 per cent in B.O.D. and 66 per cent in organic nitrogen. If large scale results prove this method to be practicable, a development of the activated sludge process comparable to that of the high rate trickling filter is possible.

Rate of Oxidation.—In 1937, more information has been presented to show the desirability of tapered aeration in the operation of aeration tanks of the activated sludge process. Spiegel, Kappe and Smith consider that the three main factors in determining the rate of oxygen utilization are

(1) Activity of the sludge
(2) Types of substances in the sludge
(3) Temperature—(rate of bioactivity)

They found that an initial maximum rate of oxygen consumption was followed by a rather sudden slowing down and then a slower sustained almost constant rate. The initial maximum rate seemed to be nearly identical for weak or average strength sewage but the period over which the maximum rate continued varied directly with the strength of sewage. The authors conclude that for a given condition of returned sludge, the required aeration period must be in direct proportion to the strength of the pre-settled sewage and that when the sewage strength is constant, the period of aeration required to produce well-conditioned sludge varies inversely with the maximum sludge activity.

Basiakina concluded from her studies that the B.O.D. of the sewage, as determined by the nitrate method with a 20 day incubation, gives the actual amount of substances biologically oxidized. She did not consider the dilution method satisfactory for semipurified sewage, as nitrification occurred during incubation. She recommended tapered aeration and stated that efficient results are obtained only when practically all of the absorbed substances were oxidized and the sludge returned to its original activity. She also developed a mathematical equation to express the amount of oxygen necessary to oxidize sewage of known strength.

Moore has found that the rate of oxygen consumption in mixtures of sewage and activated sludge can be represented as the sum of three monomolecular reactions of the same type as that used to represent the biochemical oxygen demand of sewage and polluted waters. The velocity constants of the second and third reactions, however, are considerably greater than the value generally accepted for sewage and polluted waters.

Heukelekian and Ingols observed that during the aeration of activated sludge and sewage mixtures, the maximum rate of carbon dioxide production occurs in the beginning and that the duration of the high rate depends upon the strength of the sewage. They suggest that determinations of the carbon dioxide production might be a more reliable way of ascertaining the load on aeration tanks than the B.O.D. because the carbon dioxide measurements are made under conditions more nearly like those in aeration tanks.

Sludge Bulking.—The control of sludge bulking continues to be an active problem with the methods of correction varying according to the conditions existing at the plant. According to Haywood, activated carbon applied at the rate of 4 p.p.m. to the mixed liquor before it reached aeration tanks aided in the elimination of bulking at the activated sludge plant in High Point, N. C. At San Antonio, Texas, bulking is commonly caused by insufficient air and Berg found that 1,000 cubic feet of air per pound of primary effluent B.O.D. seemed to be minimum for keeping the sludge in good condition. Temple reported that at Nagpur, India, bulking sludge could be brought back into condition in a few hours by speeding up the return of reaerated, reactivated sludge. Ely eliminated in 10 hours the bulking of sludge caused by a

large amount of carbonaceous material by the addition of fine clay soil to the aerators. Ridenour, Henderson and Schulhoff observed that the filamentous character of activated sludge remained unchanged by the addition of varying amounts of chlorine. (See also Section 5.)

Design.—Continued improvement in activated sludge plant design has made possible greater economy in construction and operation. Whittemore and Anderson have described the main features of the Southwest Side plant in Chicago which has a design capacity of 400 m.g.d. The aeration tanks will have a width of 32.75 ft., an effective depth of 15 ft. and a channel length of 1,736 ft., made up of four passes. The diffuser plate ratio of 1 to 20.2 and the detention period of five hours will be less than in some of the earlier plants. For economy, air lifts will be used instead of pumps for returning sludge. A long overfall final effluent weir chamber will concentrate the available drop at one point to give maximum oxygen absorption.

One of the notable features of the Tallmans Island plant, now under construction in New York City, is that primary tank effluent may be admitted in varying amounts at three points in the aeration tanks to provide proper distribution loading. The Wards Island plant of New York City was put into partial operation October 16, 1937, with a sewage flow of 170 m.g.d.

Freese has presented the basis of theory and practice governing the design of diffused air aeration tanks and has prepared curves to show the approximate detention period and the amount of returned sludge necessary. Although he does not claim that these can be applied in all cases, they may serve as a valuable guide to the designer when the character of the sewage is known.

Operation.—Pipe and Farmer, experimenting with partial treatment of sewage by the activated sludge process, found that at a rate of treatment 6 to 12 times that normally used, about two-thirds as much purification could be obtained. The sludge is less active than normal sludge and solids and colloidal matter seem to be coagulated by growths of filamentous bacteria. About five per cent of sludge is carried in the diffused air aeration tank, as measured by one hour settling. With more sludge, the floc deteriorates and may become septic. With partial purification, reaeration of sludge did not seem to be beneficial.

The dewatering of activated sludge has always been difficult. After Lumb and Hirst heated activated sludge for thirty minutes at a pressure of 150 pounds per square inch (184° C.), the pressed cake continued to drain and dried readily to about 25 per cent moisture in one to three weeks. Bell has continued his experiments on the dewatering of sludge. The light, solid particles in activated sludge are coagulated by adding about 63 pounds of sharp-grained dust to each 1,000 gallons of sludge and allowing the mixture to settle. After the separation, which requires three to four hours, the coagulated sludge is discharged onto drying beds and the supernatant liquor is returned to the incoming sewage.

Air filters and other purifying equipment have long been used to prevent clogging of the porous plates in aeration tanks, but when oil and smoke from smudging seriously affected the filter plates in the aerators at Ontario, California, Ely added gasoline to the main air lines at the rate of three to four quarts per day. At the end of the smudging period, the plates were as clean as when installed and the air pressure was back to normal. No mention was made of the effect of the gasoline on the purification. Rudolfs found it highly toxic to sludge digestion (see Section 3).

Industrial Wastes.—Levine, Nelson and Dye found that an experimental activated sludge plant treating packinghouse wastes operated very satisfactorily on the fill-and-draw basis but a full scale plant operated for nine months yielded average B.O.D. reductions of only 54.8 per cent. The poor results of the full size plant were attributed to great fluctuations of the waste both in concentration and in volume which upset the delicate equilibrium necessary for the successful operation of an activated sludge plant.

The Sioux Falls, South Dakota, sewage treatment plant, which has a sewage flow from a population of 31,500 and a packinghouse waste equivalent to a population of 103,000, is unique in that it combines three standard methods of treatment in one plant, viz., chemical treatment, trickling filters and activated sludge. Instead of the customary practice of aerating sewage before it enters the trickling filters, the aeration follows the filters. Bragstad and Bradney report that too much air in the aeration tanks produced nitrites and floating sludge; too little air, bulking. Careful control of the air is necessary to maintain 2.0 to 3.0 p.p.m. of dissolved oxygen in the first half of the aerator and no more than 0.5 p.p.m. in the second half. Floating of sludge occurred when the nitrite content in the aeration tanks was high, as the nitrites decomposed and gave up bubbles of nitrogen which carried the sludge to the surface. Properly controlled, the plant has operated very satisfactorily.

Henderlite stated that the activated sludge plant at Gastonia, North Carolina, overcame difficulties resulting from discharge of textile dye wastes in the sanitary sewers by the addition of 300 to 360 pounds of ferric chloride (anhydrous) per million gallons of combined sewage and wastes. Ferric chloride was added, 8 to 10 hours per day, for five days a week, the period of dye flow. The cost of $2.36 per million gallons was not considered excessive when the improved results, better plant control and condition of the stream receiving the effluent were considered.

At the Kisshoin Experimental Treatment Plant at Kyoto, Japan, Chujo found it necessary, because of the large amount of industrial wastes, largely from textile mills, to adjust the pH of the sewage before treatment in the activated sludge plant. Utilization of the digester gas, either before or after the gas was burned, proved the most economical way to reduce the pH. Treatment for five hours a day was generally sufficient.

(3) Sludge Digestion

The report of the A. S. C. E. Committee on separate sludge digestion has been issued and should prove of interest to operators and designing engineers. Sludge characteristics, plant performance, the effect of different environmental conditions and the problem of sludge disposal are discussed fully.

What is the best method of feeding the digesters when there is more than one unit available? Should each unit receive an equal part of the accumulation of the raw solids every day or should the tanks be fed in daily rotation? Some interesting observations on these questions were made at the Aurora Sanitary District by Sperry. During the period of 1933–36 the raw sludge was pumped six times a day to one digester instead of being distributed equally between the three digesters. The gas produced from the charged tank was highest the first day and decreased during the second and third days during which no charging occurred. The sludge concentration in the digesters dropped to 4 to 5 per cent due to gas flotation and the high rate of gasification. During 1936–37 the three tanks were fed each day but this did not cause the expected improvement. A greater concentration of solids had been obtained during a similar method of charging in 1932 and 1933. This was attributed to increase in the load on the plant. In the 1931–35 period the monthly load was 0.9 lb. per cu. ft. and in 1937 it had increased to 3.2 lb. per cu. ft. digester capacity. The digester capacity is 2.5 cu. ft. per capita on the basis of present population. Gas production, in terms of tank area for the two periods in question amounted to

1932–33 .....4.38 cu. ft per sq. ft.
1936–37 .....6.03 cu. ft. per sq. ft.

It was concluded that the rate of gas release per unit area had an important influence on the working capacity of a digester. The gasing rate should not exceed 4.5 cu. ft. per day per sq. ft. area. Sperry stated that a digester should have more width than depth to provide proper area for gas release.

A careful laboratory check on the nitrogen balance confirms the conclusions of others that there is no loss of nitrogen during digestion. There is a change of nitrogenous materials from insoluble form to soluble forms. In raw solids 98.6 per cent of nitrogen is insoluble. In digested sludge 56.8 per cent of the original nitrogen is in the solids phase and 43.2 per cent in solution. Thus digested sludge has a lower fertilizer value than non-digested sludge because in the common drying methods (sand beds and vacuum filtration) the liquor which contains the soluble nitrogenous materials is wasted. If these could be retained in the drying process the concentration of nitrogen would be higher than in fresh solids because the nitrogen is retained while other materials disappear. This nitrogen is also in a more available form.

Stage Digestion.—Stage digestion still attracts attention. Results of four years operation of multiple stage digestion at Los Angeles

County are presented by Rawn, Banta and Pomeroy. Four-stage digestion is accomplished by gravity segregation of the solids, the sludge being transferred from the bottom. The raw sludge consists of 33 per cent primary and 67 per cent activated sludge with 4.7 per cent solids in the mixture. The nominal detention time in these tanks varies from 13.5 to 10.3 days. Additional detention period of 27 days is provided in an open pit. Sludge to seed the tanks is taken from the pit and returned to the first tank. A heavy layer of scum formed in the first three tanks which had to be removed. Volatile matter reduction in the four tanks was 47 per cent with an additional reduction of 14 per cent in the open pit. The weight of gas produced was 107 per cent of the weight of organic matter destroyed. Stirring accomplished by the use of gas lifts failed to give any appreciable advantage over non-stirred tanks.

Hoyle reports that at Exeter, England, two-stage digestion of raw and waste activated sludge is accomplished in open, unheated tanks with a total digestion capacity of 3 cu. ft. per capita. In winter with an average temperature of 44–50° F. in the tanks the digested sludge contained 56.0 per cent volatile solids giving a loss of volatile solids of 41.4 per cent. In summer the average tank temperature was 62–65° F. The digested sludge contained 49 per cent volatile solids with a loss of 56.4 per cent of volatile solids.

Additional results on two stage digestion of the West Middlesex Main Drainage works are made available by Townsend. Digestion for 23 days of raw and waste activated sludge with a 5 per cent solids concentration in the primary tanks yielded a 50 per cent destruction of volatile matter at 80° F.

Activated Carbon.—Studies on the effect of activated carbon on sludge digestion are reported by Walker. Laboratory experiments were made with daily additions of raw sludge and withdrawals of digested sludge. Digestion was carried on at 20, 28 and 45° C. Activated carbon was added to the daily charge of fresh solids, at varying rates, computed in p.p.m. of the sewage. At 20° C. the addition of 5 to 15 p.p.m. somewhat increased the gas production. At 28° C. this advantage did not appear. When added to the sludge in greater amounts, carbon reduced the amount of gas at all temperatures. Analysis of the gas taken at a single period indicated that the percentage of methane increased somewhat with carbon additions (from 49.1 in the control to 57.0 per cent with 15 p.p.m. of carbon at 20° C. and from 56.3 to 62.8 per cent with 7 p.p.m. of carbon at 28° C.). It was also concluded that carbon increased the drainability of the sludge. The addition of carbon to the digestion tank of the city of Ithaca was followed by reduced gas production and the treatment was discontinued but it is not possible to attribute the effect to carbon additions. During the period when carbon was added daily sludge temperatures increased from 82° F. to 88° F. but during this period the air temperature was also increasing. It is not believed that the change in outside

temperature could entirely account for this rise. A noticeable reduction in odors of the carbon-charged fresh solids was evident.

Digestion of Garbage.—Interest in the digestion of garbage continues. Studies conducted at the University of Illinois Engineering Experiment Station and reported by Babbitt and associates showed that addition of garbage directly to the digestion compartment of an Imhoff tank was impracticable. Acid digestion and scum formation developed. Intimate mixing of garbage with the liquid of the digestion compartment is essential. A two-story heated (88–92° F.) separate digestion tank was operated successfully with a 30-day detention period when fed with a mixture of equal quantities of sewage and garbage solids. Elutriation of the garbage with sewage did not improve the digestion and resulted in lower gas yields due to the removal of a part of the volatile solids. Unground garbage was digested successfully but fineness of grinding was a factor in the rate of digestion.

Malcolm investigated the digestion of ground garbage in 55 gal. oil drums with daily additions of mixtures of fresh solids and garbage. The relative proportions on the basis of volatile matter were 1:1, 1:1.5 and 1:2. Sewage solids and garbage were also added separately. The raw solids were fed at the rate of 1.7 per cent of the digested sludge on the basis of volatile matter giving a digestion period of 44 days. The average temperature was 67° F. With these various additions for a period of 150 days the percentage of volatile matter at the end of the period was materially increased.

Gas production was nearly constant at 10 cu. ft. per lb. of volatile matter added for the various mixtures fed, and the methane content quite uniform. It was concluded that ground garbage could be digested readily either alone or mixed with raw sewage sludge.

Industrial Wastes.—The digestion of meat packing, corn products, canning and creamery wastes at the Cedar Rapids combination waste treatment plant is described by Green. With a contributing population of 55,000 the population equivalent was 163,000 with the heaviest loading occurring at the lowest temperatures. The packinghouse wastes are pretreated with fine screens and grease traps before entering the sanitary sewers. An equalizing storage tank is provided in order to deliver the wastes to the treatment units at a uniform rate. There are four digesters, two of which are equipped with floating covers, one with a gas holder. The fourth is an open tank. The raw sludge is pumped for two-day alternate periods to tanks equipped with floating covers. Partially digested sludge is transferred to the unit equipped with a gas holder. The covered tanks are heated to 90° F. using only the cooling water from the gas engine. At no time has there been any indication of foaming or incomplete digestion. Sixteen per cent by volume of raw sludge could be added daily for 2 to 3 days in succession without difficulty. Loading beyond this period resulted in excessive gas turbulence and foaming. The average gas recovery was 2.5 cu. ft. per capita of actual population.

Laboratory experiments conducted at Iowa Engineering Experi-

ment Station by Levine, Nelson and Dye indicated that packinghouse sludge could be digested on a batch basis at 84° F. with the production of 780 c.c. gas per gram of volatile solids (2.5 cu. ft. per lb. of volatile solids). Gasification was complete in 40 to 50 days with 90 per cent of the gas being produced in half this period. With continuous additions (30 additions in 38 days) a digestion schedule of 55 days could be maintained. It was concluded that packinghouse waste decomposed rapidly and would require less digestion period than domestic sewage solids. Digestion of these wastes in the thermophilic range was rapid but the liquor was ill-smelling and the solids did not settle readily.

The sudden upsetting of the operation of the digestion tanks at Westminster by a discharge of distillery waste is described by Blohm. The pH of the raw sludge containing the distillery waste was 4.0 while the normal raw sludge had a pH 6.8. The digester began to foam. Lime and recirculation of the sludge or chlorine abated the foaming as long as no additional distillery wastes were received.

Owing to the seasonal discharge of cannery wastes, the Palo Alto plant has become overloaded, according to Gregory and Kimball. The digestion tank is heated to 90–100° F. and the contents recirculated by a sludge pump. Peaches which floated in the clarifier were skimmed and added to the digesters. Tomato skins which settled to the bottom of the clarifier when pumped into the digester formed a dense mat on the surface which did not digest during a period of years. Foaming was experienced along with high gas production (2.5 cu. ft. per capita per day). Removal of the solid wastes at the cannery resulted in smoother operation.

Rudolfs and Setter report the results of laboratory experiments on the effect of various organic wastes such as dye, rug, laundry and wool wastes upon digestion. A retarding influence was observed with the various wastes only when comparatively large quantities were added. The retarding influence was noticed first in gas production hence it was stated that liquefying organisms are less affected than gasifying organisms by these wastes. By repeated additions of these wastes and the re-use of the sludge, sludges were obtained which could effectively digest the wastes upon which they had been developed. With larger doses longer periods were required to produce an adapted sludge. Continuous discharge of organic wastes are therefore less harmful than intermittent doses. Ripe sludge will tolerate 15 to 20 per cent of these types of organic wastes, on the basis of volatile matter, when added intermittently, while 20 to 40 per cent can be tolerated when the wastes are received continuously. Under thermophilic conditions the sludge was less sensitive to the wastes than at mesophilic temperatures.

The effect of certain toxic wastes such as copper sulfate, sodium arsenate, gasoline, sulfuric acid, waste crank case oil were studied and reported on in a later publication by Rudolfs. Copper sulfate and sodium arsenate retarded sludge digestion even when small quantities were added, as was to be expected. Gasoline when added in concen-

trations as low as 1 per cent by volume of the fresh solids doubled the digestion time. Crank case oil stimulated gas production but there was considerable scum formation and the digestion time was increased. Sulfuric acid in small quantities had little effect on gas production and digestion time but larger quantities inhibited gasification. The phenomenon of acclimatization of sludge was apparent to a certain extent even with the poisonous wastes as well as with the crank case oil. Thermophilic digestion appeared to be more sensitive to poisons than mesophilic.

Miscellaneous.—Berg conducted some experiments on laboratory scale with daily additions to determine the capacity of the tank to take care of waste activated sludge and fresh solids. The digestion of activated sludge alone on a 39-day digestion schedule resulted in poorly digested thin sludge. With a digestion capacity of 5.5 cu. ft. per capita or 40 cu. ft. per lb. of volatile matter added per day, satisfactory digestion of activated and primary sludge took place. The natural activity in the digester was found to be sufficient for adequate mixing of the incoming with the digested sludge.

(4) Chemical Treatment

The year 1937 produced comparatively little material contributing to new procedures in chemical treatment, indicating that the field of usefulness of available processes is fairly well defined until something rather radically new is presented.

Garner, in reviewing British practice, presents a scholarly historical review of the chemical treatment of sewage, which began in England in 1854 or perhaps a little earlier. This review should be of material value as a background against which some of our present processes can be evaluated, and perhaps the claims of certain patentees discounted. He concludes that in England for a long time there has been little development of new processes of chemical treatment of sewage, and that the general trend is more and more towards complete biological treatment.

Hendon, in the same symposium before the Institution of Chemical Engineers, presented the case for chemical treatment, judged from American experience, under four headings:

1. The need for a process intermediate between plain sedimentation and biological treatment, to meet certain dilution requirements economically.
2. The need for a process which can be adjusted economically to seasonal and other variations in either load or available dilution.
3. The need for an intermediate process for reducing the load on existing overloaded biological plants.
4. The need for methods of pre-treatment of industrial wastes entering sewage treatment plants.

Modern chemical treatment is able to meet these requirements economically and flexibly in many cases, which Hendon illustrates by

reference to various plants in the United States, especially Shades Valley, Dearborn, Coney Island, Colorado Springs, Denver, New Britain, Minneapolis-St. Paul, Atlanta, Cedar Rapids and Perth Amboy.

Imhoff in the same symposium, calls attention to the practical disregard of chemical treatment of sewage in Germany, except for the treatment of certain industrial wastes. He states that Jung has developed a special coagulant prepared by saturating sewage with carbon dioxide derived from flue gases, in contact with iron filings, producing ferrous bicarbonate; the sewage is then aerated to produce ferric hydroxide as the coagulant. German engineers are not impressed with the newer improvements in chemical treatment, preferring biological treatment, with some tendency to return to agricultural utilization of sewage. Bach, in his discussion, does not consider chemical treatment economical as compared with biological processes.

The divergence of viewpoint in this symposium is striking and most interesting, and is evidently affected by the conditions influencing sewage treatment in the three countries. It appears reasonable to assume that population density and the heavy pollutional load of sewage and industrial wastes on streams would require complete or fairly complete biological treatment of sewage in England and Germany, but that in the United States in large areas intermediate treatment by chemical methods may be economical and satisfactory for many years to come, until the inevitable urbanization and increase in population density forces a change to more complete biological treatment. The greater fluidity of American population (as illustrated by Colorado Springs), contrasted with the relative stability of European population, and the greater variability of flow in many American rivers, may also be a factor. It is interesting to note that eight of the thirteen new plants on the Raritan River watershed are chemical precipitation plants, which indicates the special adaptability of this process to that particular situation with its wide seasonal fluctuations in requirements.

Working with samples of sewage from various sources, Rudolfs and Gehm studied the effect of return sludge upon clarification, using various quantities of return sludge with and without additional coagulant. Ferric chloride, alum, and lime-ferric chloride were used as coagulants. Their results indicate that the use of return sludge from all three coagulants has some clarifying value, which is more noticeable when a moderate amount of return sludge is added to a weak sewage. Where a sufficient quantity of chemical is added to produce a fairly complete clarification, the practice of returning sludge may have little value, and in general it will be a question of balance between the cost of returning sludge and the additional clarification obtained. This balance will probably vary with different sewages. The return of overtreated sludge will be no more effective than the return of fully treated sludge.

The same authors have also studied the effect of stirring, both by mechanical means and by the bubbling of various gases through the sewage, upon the removal of suspended solids and B.O.D. by chemical coagulation. The results indicate that stirring without chemicals, as

suggested in this review for 1936, increases the removal of suspended solids as compared with plain sedimentation, and that a greater reduction in B.O.D. was also obtained. The mechanism of removal is apparently a physical agglomeration of finely divided or pseudo-colloidal material. Judging from their results, flocculation for periods much beyond one-half hour will not justify the additional power cost. Stirring by means of diffused air appears to have a slightly greater effect during the first half-hour than mechanical stirring, but perhaps not enough to justify the probable greater capital and operating costs of air stirring as compared with mechanical stirring. Further studies of flocculation with and without chemicals are being made, and should throw considerable light upon a very practical question in the field of chemical treatment of sewage.

Rudolfs and Ingols studied the effect upon chemical coagulation of the introduction of ground garbage, approximating the effect of the addition of the entire garbage of a community to its sewage. So many variables are involved in such experimentation (great variations in garbage characteristics and considerable variation in sewage characteristics) that any conclusions must necessarily be guarded and quite tentative, but it appears probable that the addition of ground garbage to sewage will cause only a relatively small increase in chemical cost.

Whedbee and Zeller have performed an elaborate series of studies on chemical precipitation of sewage over a pH range from 3 to 12, using principally ferric chloride, ferric sulfate, ferrous sulfate (copperas), chlorinated copperas, aluminum sulfate and aluminum chloride. The range of pH was obtained by pre-treating the sewage with either sulfuric acid, or lime or caustic soda. Although their results with the rather strong Dallas sewage may not be applicable directly to other sewages, some of their conclusions appear to be rather generally applicable. They found that preliminary sedimentation prior to chemical treatment was of doubtful value, but that return of sludge improved coagulation and removals. With ferric chloride, coagulation was most effective on the acid side, particularly at about pH 5.5. With aluminum sulfate, coagulation on the alkaline side, with lime, was preferable. With ferric sulfate, the economical point appeared to be at about pH 8.0 to 8.5, with lime, but with ferrous sulfate optimum coagulation took place at pH 9.0 or above, and potassium permanganate was needed as an oxidative protection. Chlorinated copperas appeared to coagulate over a wide range, from pH 5.5 to 9.5, and aluminum chloride had a similar wide pH range. For Dallas sewage, the coagulants were rated in the following order of effectiveness: ferric chloride, aluminum chloride, ferric sulfate, chlorinated copperas, aluminum sulfate, and copperas.

Olin, Campbell and Gauler performed laboratory tests with bentonite as a coagulant for sewage, following suggestions obtained from its use in the coagulation of water prior to filtration, and obtained results indicating that, if sufficient bentonite be added, the floc forms readily over a wide range of pH, with a prompt and effective coagulation

of colloids. Rather large amounts of bentonite were used, considerably beyond the usual range of application of chemicals, and extending up to 900 lb. per million gallons. It would appear to be advisable to try out bentonite experimentally on full scale in some existing plants.

Haywood has reviewed the uses of activated carbon in sewage treatment. Certain uses, such as odor control, appear to be plausible, but certain other uses related appear to be forcing the material beyond the economic range of its usefulness.

Operating results for a full year of the completed Coney Island plant are not yet available, but Donaldson has given some interesting data as to the preliminary operation, while experimentally trying different combinations and dosages during the construction period in 1936. From June to October an average of 261 lbs. of ferric sulfate and 100 lbs. of chlorine per million gallons was applied, at costs ranging from $6.83 to $10.80 per m.g. (the higher costs were with additional hydrated lime). The flocculators were not available during this period. With chemicals the average removal of suspended solids was 61 per cent, of settleable solids 82 per cent, and of 5-day B.O.D. 51 per cent; without chemicals these removals were respectively 44, 69 and 31 per cent. No difficulty with sludge digestion due to chemicals was encountered.

At El Paso, Texas, Yaffe has obtained fairly good results with rather less chemicals than the usual practice. Using 82 lbs. ferric chloride per m.g., he reported 87 per cent reduction in suspended solids and 74 per cent reduction in B.O.D., at a cost of about $3.53 per m.g. for chemicals. The ferric chloride is made by applying chlorine to iron turnings, and he has interestingly described his difficulties with what is apparently hydrogen binding during the generation of the ferrous chloride. (See Section 5.)

A chemical treatment plant of the Guggenheim type, treating an acid and metal plant waste combined with domestic sewage at New Britain, is described by Cunningham and Gatley. A 100,000 g.p.d. experimental plant was successfully operated before the design was attempted. The full-size plant has been in operation during 1937, but operating data have not as yet been published.

(5) Chlorination

The standard chlorine demand test limitations are discussed by Symons, who makes suggestions leading to improvement in technique. The so-called Bird Island Laboratory method was developed and a number of chlorine demand experiments were made on various sewages and under varying conditions. Since the Buffalo sewage, including considerable industrial waste, appeared to exhibit a low chlorine demand (as compared with other cities) despite good bacterial kills, the accuracy of technique was investigated. The effects of contact time, of temperature, and of high chlorine demands exhibited by industrial wastes were studied. The test developed is a spot-plate procedure and consists of graded additions of chlorine solution to a series of five separate samples of the sewage. In the first, the initial chlorine demand is

satisfied and each subsequent sample contains an increased dose. After fifteen minutes contact time the residual chlorine is read on the spot-plate with o-tolidin indicator and one infers that the chlorine demand is taken as that total chlorine dose which yields a residual of 0.1. Only in the case of weak sewages, demand 3 to 5 p.p.m. is a 10-minute contact sufficient. The final reading is taken at maximum color, which is generally less than 5 minutes. A comparison of this and other techniques indicates a serious lack of fundamental definition and a general misconception of the nature of the so-called chlorine demand. As employed it is arbitrary and of strictly local applicability. Properly defined and interpreted, as a rate rather than a fixed quantity, it possesses useful possibilities.

Rudolfs reviews sewage treatment practice abroad and notes that in England the use of chlorine as an integral process is in its infancy as compared with its rather widespread use in the United States. Apparently it is so little used in continental Europe as to be not worth mentioning. This he interprets as due to the fact that changes are made slowly, that findings elsewhere may not be readily accepted, and that the need is not so pressing nor benefits so readily demonstrated as in this country.

A study by Charlton and Levine adds to the theoretical knowledge of the mechanism of disinfection by chlorine and certain of its compounds. Their experimental evidence stresses the significance of pH values upon germicidal power and indicates the effects of concentration and temperature. Specific results with reference to the increased killing power of hypochlorites at lowered pH, as compared with the effect under more alkaline conditions, are most applicable to sewage problems.

The use of chlorine for a distinctly new purpose is described by Faber in short plant-scale tests at the Woonsocket activated sludge plant. Chlorine was applied as a gas mixed with diffused air employed for floating grease in a preliminary skimming tank. This was for the purpose of destroying the protective colloid effect of protein material holding grease in an emulsion which prevented its release. Chlorine doses of approximately 1.5 p.p.m., based on total sewage flow, with 6 minutes aeration gave an increase of 2 to 4 times the grease accumulated by the usual aeration. The domestic sewage contained wool scouring wastes five days each week and twice the usual weight of grease was obtained on these days. On straight domestic sewage the increase was four times that usually obtained. The dose applied produced no residual in the skimming tank effluent.

Chlorine for Disinfection.—Hoskins notes that in the solution of stream pollution problems it appears a basic consideration as well as sound economics that the minimum degree of sewage treatment required for each water-course must be established. On such a basis, primary treatment with effluent chlorination, as recommended by the International Joint Commission in 1916, will be suitable for the large plants now building at Detroit, Buffalo, and Niagara Falls. Comple-

tion of these plants will leave no major Great Lakes city lacking sewage treatment.

At Butler, Pa., a change from effluent to influent chlorination is reported by Haseltine. During a relatively short period of operation, partial prechlorination apparently produced greater B.O.D. and solids removal through one clarifier than had previously resulted from two clarifiers in series. Definite conclusions must await a longer study.

Chlorine for Odor Control.—Wisely, in a comprehensive article, reviews the general application of chlorine for odor control at sewage plants and Enslow emphasizes the economy of up-sewer application to maintain non-septic conditions. The assurance of odorless operation through chlorination for this purpose has made it possible, according to Rudolfs, to locate the new sewage treatment works of New Brunswick, N. J., practically in the heart of the city. The saving of an expensive outfall to a remote location and of pumping costs of $18,000 annually were a result. He points out that such a location would not have been acceptable a few years ago because of odor possibilities with no ready means of prevention.

Marshall describes odor reduction at one of the Geneva, N. Y., treatment plants by application of chlorine to the screened sewage. The chlorine demand at normal flows averages 16 p.p.m., but this rises to as much as 43 p.p.m. when beet wastes from a local cannery are received. In operation it has been noted that organic coloring matter can be bleached from the beet wastes with very large chlorine doses.

Where low sewer grades and high temperatures are responsible for sewage decomposition en route to the plant, and when these causes cannot be corrected, chlorine has been found of value as a corrective. O'Neill describes odor control at the new Rayne, La., Imhoff plant, due to stale sewage received at the plant, through possibility of varying point of application. Either raw sewage, tank effluent or filter effluent may be dosed.

Applying chlorine to industrial wastes, before discharge into the sewer, is recommended in certain cases by Geyer to suppress septization, odor production, sewer attack and interference with plant operation.

Chlorinated iron, either as ferrous or ferric chloride, produced by treating scrap iron with a solution of chlorine gas in water, is proving to be an effective and economical method both for odor control and for coagulation under certain conditions. Hicock describes such an iron chloride generator at Glendale, Ariz. The sewage treated (0.5 m.g.d. flow) is rankly septic as it reaches the plant but is readily treated by this process. In addition to the elimination of hydrogen sulfide, a 75 per cent reduction in suspended solids is reported. At the Tovrea Packing Company's plant in Phoenix, Ariz., a similar solution, prepared from baling wire, is used as a coagulant for wastes from meat packing, according to Carollo. A dose of 20 to 24 grains per gallon results in a reduction of B.O.D. of from 4,000 to 800 p.p.m. Some 7,000 pounds of solids are removed from a daily flow of 0.2 m.g.d. The sale

of grease and digested sludge are reported to return $20 daily at an entire operation cost of $18. Chlorination of the effluent for disinfection is also practiced.

Operating difficulties in the preparation of iron chloride solutions are described by Yaffe at the El Paso, Texas, plant. Apparently, hydrogen gas produced in the reaction produces a film on iron borings and reduced effective contact between chlorine and iron. Stirring each hour or so to release the hydrogen bubbles was necessary for uniform solution strength. Alternate layers of tin cans and iron borings (each about 1 to 2 ft. in thickness) in the generator, solved this difficulty. The cans are more slowly acted upon and appear to prevent the hydrogen film accumulation. Iron to supply approximately 72 lb. ferric chloride per m.g. is applied and the sewage is settled. Reductions of approximately 85 per cent of the suspended solids and 65 per cent of the B.O.D. are obtained with a dose of about 9 p.p.m., computed as $FeCl_3$.

Chlorine for Correction of Foaming.—Beneficial effects of prechlorination in control of foaming Imhoff tanks are noted at the Tonawanda, N. Y., treatment plant by Samson. During the summer months less acid is developed and the previous foaming conditions are eliminated. Treatment has proven successful for two years and because of the decrease in chlorine demand of the settled sewage, the post chlorine dose has been reduced. This divided application of chlorine has resulted in a saving of about 14 lb. chlorine per m.g. during the year.

Foaming conditions in primary and secondary clarifiers and in the digester of the Westminster, Md., plant, caused by distillery waste, were corrected by direct application of hypochlorite. According to Boyle, digester conditions resulted in acid production and a pH of below 4.0. Subsequent addition of packinghouse wastes also proved amenable to control by the same treatment. (See also Blohm.)

Chlorine and Sludge Bulking.—Further reports on chlorine application to return activated sludge for control of bulking have appeared from several plants where the method is in use or has been experimented with. In a discussion, Enslow gives an explanation of the type of bulking in which this method may be of value. The presence of filamentous organisms indicates oxygen depletion, and control of biological activity by sludge chlorination may prove beneficial.

The method has been studied by Ridenour, Henderson, and Schulhoff, at the Marlboro, N. J., plant where hospital wastes are handled with domestic sewage. Examination of the floc showed it to consist almost entirely of fungus growths. The chlorine dose applied ranged from 3.1 to 72 per cent of the chlorine demand of the sludge. Careful chlorine application neither reduced the numbers of filamentous organisms nor changed the settling characteristics of the sludge; nor was the activity of the sludge, with respect to purification, reduced as might be expected.

Smith, who first reported on this method of control at Lima, Ohio, makes routine microscopic examinations of his sludge and is prepared to chlorinate, wherever the need is indicated by increase in filamentous

organisms. At Lancaster, Pa., the method has led to control of filamentous organisms, according to Weist. Return sludge chlorination in doses of 2 to 18 lb. per m.g., on the basis of sewage treated, proved an effective measure until gas-house waste added to domestic sewage upset the entire plant.

The use of this method at the Houston, Texas, South Side plant is described by Pralle. The plant has been overloaded in both aeration and sedimentation capacity for a number of years. Since May, 1937, chlorine has been applied to the return sludge (5.34 p.p.m. of chlorine to sludge volume) with a reported satisfactory improvement in plant effluent. Microscopic examination shows distinct reduction in number of *sphaerotilis* organisms. Control of chlorination, at least to the point where no excess is present, has been shown to be necessary.

(6) Industrial Wastes

Although the published literature of 1937 appears to include rather less than the normal number of studies of industrial wastes and processes for their treatment, there has been an apparent tendency to give greater attention to the effect of industrial wastes upon the operation of existing sewage treatment plants and a greater tendency to make use of the concept of "population equivalent" of an industrial waste, and its implications.

Fales presented an able and very inclusive discussion of the effects of various industrial wastes upon sewage treatment processes, before the joint session of the American Public Health Association and the New York Sewage Works Association on October 8, 1937. A. D. Weston, in his discussion of this paper, contributed summaries of recent work of the Lawrence Experiment Station on the treatment of wastes from distilleries, elastic webbing plants, paper mills and wool scouring, and on dyes, leatherboard, latex, yeast and gas wastes. Fales recommends that certain types of wastes, which he enumerates, be entirely excluded from the sewer system, and that other designated types of wastes be pre-treated. He also believes that cities should have adequate legal control over the discharge of industrial wastes into their sewer systems.

Geyer has also presented a general discussion of the same subject, and Oeming has discussed Michigan's experience with industrial wastes in municipal sewer systems.

Blew has presented data and discussions on the economic phases of industrial wastes disposal, and particularly has called attention to the savings to industry, as well as the reduction in treatment plant loading, which have resulted from various reclamations and process changes in industries. Recirculation in the pulp industry, caustic soda recovery in mercerizing plants, grease recovery in wool scouring, production of cattle food from distillery slops, etc., are examples. He suggests, both for economy to industry and for better operation of sewage treatment plants, one or more of the following measures, according to applicability:

1. Increased use of closed systems.
2. Improved processes of manufacture.
3. Research in the utilization of by-products.
4. Reduction in the volume of wastes which are difficult to treat, by separation from plain or inoffensive drainage.
5. The combination of wastes of different characteristics (*e.g.* acid and alkali) to neutralize each other.
6. Conservation of heat losses by installation of heat exchange systems.

He also suggests that steel construction in industrial pre-treatment plants may prove an economy as compared with concrete.

Hurley calls attention to the fact that comparatively few factories have either the available space or the personnel for effective treatment of their wastes, and believes that factory pre-treatment should be kept at a minimum. He advises agreements or contracts between industrial plants and the sewage treatment plants, by which the excess cost of treatment at the municipal plant is paid by the industries.

At present engineering opinion on the subject appears to be rather divergent, but the various views may be grouped generally as follows:

1. Completely exclude the industrial waste from the sewer system, and require that it be handled separately at the sole cost of the industry.
2. Receive the entire waste without restriction or extra compensation.
3. Receive the waste, either with or without partial pre-treatment, and make an equitable charge for the excess cost of treatment.
4. By persuasion or compulsion require the industry to eliminate the grosser part of the treatment load.

As an example of the method of exclusion, Blohm describes the situation at Westminister, Md., where in the second year of operation the twice-a-day discharge of distillery waste caused severe foaming, and excessive load of solids on the trickling filters. The distillery wastes were finally excluded from the sewers, after various expedients had failed to reduce the trouble.

Shaw observed and measured the effects of winery wastes, principally still slops, upon the lower reaches of the Mokelumne River in California. Fish life was destroyed, apparently by oxygen deprivation during increased pollutional intervals resulting from intermittent discharge. These wastes have been excluded from the river, and the California Wine Association has begun a program of study of methods for their treatment.

As an example of the third method of procedure, Green has given an excellent detailed description of the steps leading up to the adoption of a joint disposal of industrial wastes and domestic sewage at Cedar Rapids, Iowa, with the excess costs, both capital and operating, being borne by the industries. The paper is extremely interesting in illustrating that it is possible, by frank discussion and careful analysis of the costs, to arrive at an acceptable basis for the allocation of charges

for the excess costs of industrial wastes treatment, and to have these accepted by industry when they are certain that the charges are founded on engineering, not politics.

As an example of the fourth method, Gregory and Kimball have described the difficulties at Palo Alto, California, with cannery wastes, and the improvement in operation resulting from the cooperation of the cannery in screening out the coarser solids. (See Section 3.) A somewhat similar situation at Danbury, Connecticut, has been described by Bogert. Here a thick mat of fur from the hat factory wastes caused much trouble on the digester surfaces and on the sand filters. A new plant, with a detritor, fine screens, sedimentation and trickling filters appears to have improved conditions, but one wonders whether fine screening and settling at the hat works might not have been equally effective, saved the cost of a new plant, and reclaimed waste fur with a by-product value.

As an example of by-product recovery and utilization as a means of minimizing pollution of streams by industrial wastes, Westland describes the use of a lignin road binder, soil stabilizer and dust palliative made from sulfite pulp waste, now being marketed in the Pacific Northwest. In this case, however, the lignins are the less objectionable part of the waste, the wood sugars causing most of the pollutional load on the streams.

Kobe has described the various by-products which are obtainable from sulfite waste liquor, ranging from baker's yeast and alcohols through adhesives, road binders, fuels, and tanning extract to synthetic plastics, vanillin and fertilizer. There is hope that by-product recovery from sulfite pulp waste has now reached a point where it is practicable and reasonable to insist upon the exclusion of this highly polluting material from streams, without economic detriment to the industry.

A comprehensive and well-documented survey of developments in the treatment of industrial wastes since 1934 was presented by Rudolfs before the joint session of the American Public Health Association and the New York Sewage Works Association on October 8, 1937. In his discussion of Rudolf's review, Hoover presented some results of his own experimental work, and particularly called attention to the need for more rapid methods of analyzing industrial wastes.

Green and McIntyre, in treating packinghouse waste at Cedar Rapids, Iowa, found fine screening decidedly beneficial as a preliminary treatment, and found that mechanical flocculation for thirty minutes made possible a materially greater removal of suspended solids and B.O.D., making the use of chemicals for coagulation unnecessary until the plant loading is materially increased. They found that for sedimentation after flocculation the following limits should be observed:

1. The overflow rate should not exceed 850 gal. per sq. ft. of basin surface per day;
2. Not less than 80 minutes detention period;

3. A minimum depth of 5 feet;
4. The velocity of the flocculated liquid in pipes and channels should not at any point exceed 2.5 ft. per second.

They conclude that packinghouse waste can be treated with domestic sewage, by ordinary methods, up to ratios of 1 to 4 for B.O.D., and 1 to 5, volumetrically.

It is intresting to compare their results with those of Levine, Nelson and Dye at Mason City. There shallow, washable and de-cloggable primary filters at 4 m.g.a.d., followed by settling and final filtration on filters 8 ft. deep at 3 m.g.a.d., produced effluents with 42 p.p.m. B.O.D., and an overall reduction of about 93 per cent in B.O.D.

Bragstad and Bradney have described the reconstructed plant at Sioux Falls, South Dakota, which treats a combined domestic sewage and packinghouse waste. Chemical precipitation, activated sludge and trickling filters are combined in the treatment process. Considerable difficulties in operation have been experienced, probably due largely to wide fluctations in flow, which are almost invariably detrimental to the activated sludge process. This difficulty has been apparently overcome by re-circulating the accumulated effluent from the trickling filters to smooth out the flow through the plant. An excellent effluent has been produced.

Jenkins, working in England with milk wastes, indicates that storage for one day improves the operation of filters, by splitting the milk solids to simpler componuds; a reduction of about 25 per cent in B.O.D. by such storage is obtained at Rothamsted. This stored waste was diluted 1 to 6 or 1 to 4 with effluent, to a B.O.D. of 200 to 300 p.p.m., and then treated on trickling filters in tandem. It was found that double filtration gave more dependable results and required less careful control than activated sludge treatment. The order of dosing the filters was periodically reversed at three weeks' intervals to keep them from clogging. Using the activated sludge process, better results were obtained by aeration of the undiluted waste for a long period, than by aeration of diluted waste for a shorter period.

Szogo describes Nolté's process of treatment of beet sugar wastes, in which acid fermentation is first applied, after which the waste is treated with lime and subjected to a second alkaline fermentation.

Snell found that fiberboard waste had no appreciable recovery value, and was best treated by simple lagooning. One day's settling produced a liquid waste of about 20 p.p.m. suspended solids, which did not putrefy appreciably.

The Report of the West Riding of Yorkshire Rivers Board (1934–1937) by Garner indicates that wool scouring wastes can be successfully treated by first passing through grit (sand) chambers, followed by acid treatment and filtration to remove the wool grease. The acid effluent is then treated with lime, settled, and re-filtered prior to disposal. The lime sludge is dried and sold for use on agricultural land. Weston has also described the recovery of wool grease by acidification

and centrifugalization, and Faber has suggested that the use of chlorinated air will increase the efficiency of wool grease separation. (See Section 5.)

Three processes for the removal of phenols from the wastes from gas and coke plants are described by Goesmeier-Kres. These are the Emschergenossenschaft, Lurgi activated carbon, and the I. G. Farbenindustrie tricresyl phosphate processes.

Henderlite at Gastonia, North Carolina, has used ferric chloride (300 to 360 lb. per m.g.) on combined dye wastes which were disrupting the operation of an activated sludge plant, particularly when the wastes arrived in batches. The use of ferric chloride in the aeration tanks produced a 75 to 90 per cent reduction in color on the sulfur dyes and the vat dyes, increased the removal of suspended solids and B.O.D., and eliminated sludge bulking. The added cost was about $2.36 per m.g., or about 6.5 per cent of the total operating cost.

Pruss describes the extensive sedimentation works of the Ruhrverband for keeping pollution from coal mines and heavy industries out of the Rhine.

Bach calls attention to the "tauchkoerper," variously called a contact aerator or tank filter, which is being successfully used in Germany on various industrial wastes. He claims it is fairly stable in operation, acts as a de-colloidizer, helps to remove oils and greases, and reduces phenols. It can be used either as a partial treatment preliminary to the actviated sludge process, or as a final treatment.

(7) Mechanical Equipment

During the past year relatively few articles have been published descriptive of the many new and important developments in mechanical equipment for sewage treatment, and those which have appeared have frequently been lacking in data as to efficiency of performance. This paucity of readily available information is detrimental to development of the art of sewage treatment, for suitable mechanical equipment of demonstrated worth is essential to the proper functioning of any process of treatment.

The problem of screenings handling by grinding and return to the raw sewage has been studied in several places. Marshall and Merz have reported upon a test installation of the fixed cutter type at Milwaukee which handled up to 45 cu. ft. per hour of screenings from a bar screen having one inch spacing. At Paola, Kansas, Mitchell stated that a similar grinder had given satisfaction on a plant of 350,000 gallons a day capacity, handling 3 to 4 cu. ft. of bar screenings in 4 to 6 minutes, using a 3 h.p. motor.

Rudolfs has presented a summary description of methods and equipment used in England for acid precipitation of sludge from sewage containing large proportions of industrial wastes high in grease content and for extraction of grease from sludge.

Interest is maintained in use of sewage gas for power. Walraven has presented an additional valuable article in which he indicates that

of the total heat in digester gas the recovery will average 75 per cent, made up of 21 to 26 per cent as work, 30 to 37 per cent as heat from the jacket water and 17 to 22 per cent as heat from the exhaust gases. He estimates that one brake horsepower may be developed from each 480 connected population. Hydrogen sulfide content up to 0.1 per cent had no apparent detrimental effect upon the equipment.

An interesting power hookup at Peoria, Illinois, is described by King and Lockwood wherein the generator at the treatment plant is interconnected with the local power company's lines through automatic relays so that when the plant needs more power than it can generate, it is drawn from the power company's lines, and when excessive power is generated, the surplus is returned to the power lines.

From England, Watson reports that Birmingham is using as little fuel as 8,800 B.T.U. per brake horsepower and that the trend is toward engines that will burn both oil and gas so as to make the plants wholly independent of outside sources of power.

In a series of articles, Streander has traced the development of incineration following mechanical dewatering of sludge and described the operation and equipment for the various types of incinerators now available. He likewise presents the potential power-producing possibilities under conditions of high volatile and low moisture content.

Equipment and facilities for sludge conditioning, return and incineration, as developed for the 9 m.g.d. Guggenheim Process chemical treatment plant at New Britain, Connecticut, are described by Cunningham and Gatley.

The equipment for 2-stage destructive distillation of sludge, included in the Putnam Process of sewage treatment, as installed at St. Charles, Illinois, is described by Klassen. Here the final product is screened and the fine powder is returned to the raw sewage as "carbon" to assist in precipitation of solids.

Developments in equipment for the down-flow type of magnetite filters, as installed at Denver, Minneapolis and Cleveland (Southerly Plant), are described by Zack, together with information as to accomplishments and costs of installation and operation.

Additional information as to equipment available and power requirements for dewatering of sewage sludge by vacuum filters of varied makes has been given in articles by Pitkin, Fedeler, Zack, Kendall and others.

Crawford has contributed an analysis of the controlling factors for selection of motors, and Murray a discussion of the important problem of lubrication of equipment. Tennant, Van Norman, Wyman and Ely have discussed the advantages and also the deficiencies and limitations of a wide range of items of equipment as developed during operation of sewage treatment plants at various locations.

(8) Stream Pollution

The year 1937 has witnessed some interesting developments in the field of stream pollution and its control, both in the United States,

where legislators have been endeavoring to set the stage for a more concerted joint attack on the problem by Federal and State governments, and in England and Germany, where emphasis is being placed on the more technical aspects of waterways sanitation as distinguished from its legal side, which in these countries has been established on a reasonably firm basis for a number of years.

Legal and Legislative.—In the United States, where public sentiment has been crystallizing rapidly in favor of more active federal participation in stream pollution control, progress in this direction has been retarded through failure on the part of national lawmakers to agree as to the form of legislation which will secure the most effective administrative machinery for such control. Following the passage of the Vinson Bill (H.R. 2711) by the House of Representatives in 1936, and the recall and tabling of its original companion Barkley Bill (S. 702) by the Senate, an amended measure was passed by the latter body, containing some of the more drastic punitive features of the Lonergan-Pfeifer Bill (S. 13 and H.R. 3419). These being unacceptable to the supporters of the Vinson Bill, both measures were referred to a joint conference committee, which thus far has failed to reach an agreement on a compromise measure acceptable to both parties of the controversy. Meanwhile, sentiment favoring the Vinson Bill has been recorded by national public health, medical and engineering societies and by official interstate health organizations such as the Conference of State and Territorial Health Officers. Support for the amended Barkley Bill, containing punitive features similar to those embodied in the Lonergan Bill, has been furnished mainly by the sportsmen's and wild life conservationist groups, who appear to favor strong federal control rather than federal-state cooperation such as that provided in the Vinson Bill.

Despite the temporary deadlock in federal legislation, definite progress has been made in the formulation of interstate anti-pollution compacts. Under authority extended by the 74th Congress in 1936, states in the Ohio Valley have been proceeding with the organization of an interstate treaty commission, members being appointed by the governors of respective states. An interstate sanitation compact has been drawn up by New York, New Jersey and Connecticut for controlling pollution of the harbor and tributary waters of the New York metropolitan district. Sewage from 12,000,000 people and wastes from 100,000 industries are discharged into these waters. The three states of Minnesota and North and South Dakota have agreed to carry out a joint program for full use and control of water in the valley of the Red River of the North, which is an international stream draining into Canada. This agreement includes regulation of pollution.

In a review of English administrative practice in stream pollution control, Rudolfs notes the well-ordered legal system which has been evolved in that country since the passage of the Rivers Pollution Prevention Act of 1876. Under this system, entire watershed areas are under single rivers boards, in which are represented both local public authorities and waste-producing industries. Six rivers boards are

now in operation. Loans for treatment works can be raised by local authorities only after obtaining sanction of the Ministry of Health, to whom plans and specifications must be submitted for approval. In effect, the relationship of the various authorities provides that: (1) rivers boards are responsible for pollution abatement; (2) the Ministry of Health ensures sound engineering, and (3) local authorities take care of construction and operation.

The English system as above described appears somewhat in contrast to the present legal situation in some of our states, as summarized by Koon, who concludes:

"A consideration of the legal aspects of stream pollution precipitates a study of the chaotic character of legislative attempts to control a vexatious problem of ever-increasing importance. The welter of conflicting statutes and doctrines of the common law aggravates the perplexity of the problem by failure to accept the irrefutable tenet that ultimate purification cannot be attained overnight by legislative or judicial fiat. Major considerations of a practical and highly technical nature are inappropriately approached by legislative assemblies and courts, and in the final analysis, the rigid application of legal rules must be fashioned to yield elasticity to practical necessities of the situation in hand."

The vagaries of our state legal systems above described are strikingly exemplified by the situation noted by Howard in New Hampshire, where the State Board of Health, though empowered by regulations based on state laws to prevent an increase in existing stream or lake pollution, has no authority to require sewage treatment on existing systems except through an act of the legislature or the institution of proceedings against a public nuisance.

Surveys of Water Pollution.—Reports of important surveys of water pollution have been issued during the past year. An excellent report by Messrs. A. D. Weston and associates has dealt with the discharge of sewage into Boston Harbor and its tributaries, which in 1935 were receiving the sewage of 1,833,160 people. No serious oxygen depletion was noted in the main harbor waters, but areas of sleek and objectionable floating matter have affected the shores and bathing. Certain areas are so affected that bathing has been stopped. The total amount of sludge discharged daily is estimated at 80 tons dry solids. The engineers recommend continuing the exclusion of surface water, storm water and infiltration from sanitary sewers, control of bathing beaches and, in due time partial treatment of the sewage, estimated to cost around $14,470,000.

An outstanding report from Great Britain has been the third report of the River Tees survey, dealing with the non-tidal reaches. Two previous reports have been concerned, respectively, with the hydrographical survey of the river and with the chemical and biological studies of the Tees estuary. The present report shows that in the unpolluted upper section of the river little variation occurs in its chemical and biological composition, whereas in the lower polluted section the discharge of sewage is followed by marked changes in the dominant species of algae and in the chemical constituents associated with organic pollution. These changes are related to season and temperature,

organic decomposition being most rapid in the summer. Diurnal variations are noted in the rate of decomposition and correlation of the growth of the sewage fungus *Sphaerotilus natans* var. *cladothrix* with sewage. No seasonal variation was found in the animals of the river except in the insect larvae, in which variations appeared to be inherent rather than due to external conditions. Aside from its local interest, the report is of great general value because of the thoroughness and comprehensiveness with which both the chemical and the biological conditions associated with various degrees of pollution are described and illustrated by numerous charts, drawings and microphotographs. It is a highly distinctive contribution to the literature of water pollution, worthy of careful study by all students of the subject.

Two other recent reports of water pollution surveys from Europe are worthy of note. The first deals with a study by the Scottish Advisory Committee, of the River Carron in Scotland and its tributary, the Bonny Water, which receives both sewage and wastes from dye and paper mills. An interesting development noted in this connection has been the installation of treatment plants for synthetic dye wastes, whereby sulfuric acid, nitrobenzene and aniline are recovered, solids are removed and irregular discharge of acid and alkali wastes in large quantities is avoided. The second report by von Gonzenbach deals with a survey of Lake Zurich in Switzerland, from which it is concluded that water supply intakes in the lake should be located at depths of 100–130 feet; that more careful attention should be paid to the location of outfalls with reference to water intakes and lake currents; that to protect banks and bathing places domestic and industrial wastes should be mechanically treated to avoid sludge accumulations, and that pollution from dumps of agricultural waste and manure and of the surface by oil should be controlled by police regulation.

From the U. S. Bureau of Fisheries has been issued a report by Ellis, presenting the results of a comprehensive field survey of fish life as related to pollution of inland streams in various parts of the United States. From this survey it is concluded that the minimum D. O. requirement for streams supporting a good variety of native fish approximates 5 p.p.m. The extreme range of pH found in waters containing fish was 3.9 to 9.5, the general range being 6.3 to 8.6 for lowland streams, with mountain streams more acid. Specific conductance offers a ready method for detecting salt and acid pollution, a value exceeding 1,000 mhos. indicating pollution, except in the more alkaline regions. The lethal effects on fish life of 30 types of industrial waste and of 114 substances found in stream pollutants are described.

Industrial Wastes Pollution.—In the foregoing reports a considerable amount of attention has been given to the effects of various industrial wastes on streams and to methods for overcoming these effects. Dealing more specifically with a somewhat unusual problem of industrial wastes pollution is a paper by Shaw, in which he discusses the results of a study of pollution of the Mokelumne River by winery wastes, which in recent years have seriously affected fish life in

the river, notably in having caused an alarming decrease in the runs of migratory salmon. With five wineries handling 110,571 tons of grapes during the 90-day season of 1935, the sewage-contributing population equivalent of the wastes discharged from these operations is estimated at 224,000 with a maximum of 384,000 at the peak of operations. Grab samples of the waste showed an average of 6,800 p.p.m. oxygen consumed, 3,500 p.p.m. 5-day B.O.D., 8,000 p.p.m. total solids and pH 4.0. As the result of the findings, further discharge of slop and other concentrated wastes into the river has been prohibited.

Cannery wastes have presented a serious problem in California, as noted by Gregory and Kimball. In Washington and Oregon, wastes from canneries and from pulp and paper mills have caused much concern, as noted by Green, with respect to pollution of streams and tidal waters. Damage to shellfish by sulfite waste has been claimed in this connection. The coincidence of low stream flows with the seasonal peak of cannery operations has aggravated the deleterious effects of these wastes. Public water supplies are not seriously involved, but rather the fishing and recreational interests, which constitute one of the State's most valued assets. (See Section 6.)

In the Ohio River basin, acid mine drainage constitutes the greatest single source of industrial pollution, the total acid pollution from bituminous mines being estimated by Tisdale as amounting to over 15,000,000 pounds daily. The most effective remedy has been found to be air-sealing the mine openings, which program has been undertaken on a large scale by W.P.A. labor, under cooperative supervision by the U. S. Public Health Service and the sanitary engineers of the interested States. According to Tisdale, Ohio recently reported that the mine-sealing work in that State had reduced the daily acid pollution by 200,000 lbs. West Virginia had effected a reduction of 240,000 lbs. daily up to the middle of 1936, the sealing of 405 abandoned mines having reduced the acid load more than 50 per cent from these mines. In West Virginia, 1,358 of the 2,212 mines are abandoned.

General.—In a recent review of progress in stream pollution control, Baity notes that of the 130 millions of population in the continental United States, about 65 millions are sewered. Of these 65 millions, about 25 millions are served by sewage treatment in some degree and 40 millions discharge untreated sewage into streams and lakes. During the past five years great progress has been made in sewage treatment under the impetus of Federal relief programs. Through the expenditure of some $600,000,000 during this period, it is estimated that there has been an increase of more than 10 millions of sewered population and of more than 70 per cent in the population served by sewage treatment. When, however, as Baity states, "it is considered that the effect of all existing treatment plants is to reduce the pollution load by not more than a population-equivalent of about 10 million people, emphasis is given to the problem which lies ahead." This, in brief, may be said to summarize the present situation in the United States with respect to stream pollution, though signs of encouragement

are evident in the general awakening of the country to the significance of the problem.

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STUDIES ON THE CLARIFICATION STAGE OF THE ACTIVATED SLUDGE PROCESS *

VI. HYDROLYSIS OF STARCH BY ACTIVATED SLUDGE

By H. Heukelekian and R. S. Ingols

Associate and Assistant, Division Water and Sewage Research, New Brunswick, N. J.

Insoluble and colloidal substances must be hydrolyzed before they can become available as sources of food and energy for bacteria. In a previous paper (4) it was shown that oxidation played an important role during the clarification stage of activated sludge and that sewage-activated sludge mixtures possesed a mechanism capable of a high rate of oxidation. Since clarification entails the removal of particulate substances it is essential to demonstrate that activated sludge-sewage mixtures have the necessary hydrolytic mechanism for organic material which can not be utilized directly. Although starch is not present in normal domestic sewage in appreciable quantities, it was selected for use in these tests because of the convenience with which the hydrolysis can be followed. If it can be shown that activated sludge which normally does not have starch as a substrate possesses the mechanism for the hydrolysis of starch, then it can readily be accepted that other hydrolytic mechanisms for substances which form the normal ingredients of sewage are likely to be present.

Methods

Two procedures for the determination of the diastatic activity were employed. In the first method different quantities of the material to be tested were placed in test tubes with a constant quantity of starch (10 mgm.). Bacterial activity was inhibited by the use of toluene. The samples thus prepared were incubated at 37° C. for 24 hours. The presence or absence of starch was detected at the end of this period by addition of a solution of iodine to each tube. The smallest amount of the material tested which gave a negative starch test, at the end of the incubation period, was thus determined. The unit of diastatic activity is expressed as the mgm. of starch hydrolyzed by 1 c.c. of the material tested.

In the second method the starch was added to the material to be tested and the starch disappearance noted at the end of definite intervals of aeration in the absence of toluene. The results are expressed on the basis of the time required to hydrolyze completly the amount of starch added. The aeration was conducted at 20° C.

Results

Standard methods of enzyme study call for the incubation of a substrate with the enzyme for a given period of time in the presence of

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an antiseptic. Toluene is generally used for the study of diastase and so the presence and relative quantity of diastase in sewages and sludges was determined with toluene. A few typical results were as follows:

Nature of Material	Source	Volume Required to Hydrolyze 10 Mgm. Starch	Units of Diastase Activity
		C.c.	
Activated sludge	Hillsdale	4	2.5
Activated sludge	Madison	3	3.3
Activated sludge liquor	Hillsdale	25	0.4
Sewage	Highland Park	5	2.0
Sewage	Highland Park	1	10.0

The units of diastatic activity were calculated as the mgm. of starch hydrolyzed by one c.c. of material. It was found that sewages varied more in activity than sludges. The supernatant liquor from the sludge has no apparent diastatic activity, since 25 c.c. gave very little change in the blue color of the starch.

The different units of the activated sludge plant at Hillsdale, N. J., were studied to determine the variations in the diastatic activity as the sewage flowed through the plant. The following results were obtained:

	Volume Required to Hydrolyze 10 Mgm. Starch	Units of Diastatic Activity
	C.c.	
Raw Sewage	20	.5
Settling Tank Effluent	20	.5
Pre-aeration Tank Effluent	20	.5
Aeration Tank Influent	15	.7
Aeration Tank Middle	10	1.0
Aeration Tank Effluent	10	1.0

The diastase content of sewage was very low initially and increased only slightly after passing through the aeration tank. The activated sludge contributed some diastatic activity and the total diastase content of the mixture increased slightly with aeration. The diastatic activities of these samples were lower than any of those given previously, and the results indicate the large variations possible.

The standard method of enzyme study used in the above experiments represents conditions which permit determination of the quantity of diastase. The purpose of the present study was the determination of factors involved in the hydrolysis of starch during the aeration of sewage with activated sludge, rather than the enzyme diastase, so that the method of following the disappearance of starch in aerating activated sludge or mixtures was substituted for the first method.

When strach (100 p.p.m.) was added to activated sludge and aerated rapid changes were obtained in the color from the starch-iodine test. The original starch solution gave a blue color with iodine, but the

supernatant from the starch-sludge mixture contained a definite purple tint, although the tests were made as quickly as possible after mixing. The purple tint increased in intensity while the blue decreased, and after about 20 minutes the blue had disappeared. The purple color faded to a red and imperceptibly from this to the color of the iodine itself. The complete disappearance required 1-1½ hours of aeration. At no time during the disappearance of the starch could any color be noticed on the sludge or in the liquor surrounding the settled sludge particles. These color changes could be easily followed when the sludge was filtered off.

Several other methods of following the hydrolysis of the starch were studied. The hydrolysis of starch yields glucose. A method (6) for determining glucose in small quantities was used to determine whether any free sugar developed in the liquor during starch hydrolysis. The following results were obtained when 500 p.p.m. starch was aerated with activated sludge:

Aeation period in minutes	0	15	30	45	60	90	120
Glucose recovered in p.p.m.	0	10	15	15	19	22	36

Starch disappeared at the rate of about 1 mg. per minute (starch-iodine color tests), but the sugar appeared in the liquor at a much lower rate after the first few minutes of aeration. This lower rate of sugar appearance may be due to the utilization by the sludge of part of the sugar produced from the starch. That activated sludge can utilize sugar was shown by following the rate of disappearance of 100 p.p.m. sugar during aeration of the sludge:

Aeration period in minutes	0	15	30	45	60	90	120
Sugar remaining in p.p.m.	93	92	92	75	75	63	50

These results indicate that sugar is utilized in the aeration of activated sludge and that the rate is slower than for starch.

Another indication of the hydrolysis of starch and the utilization of the glucose may be obtained by measuring the carbon dioxide (3) produced by activated sludge. As an example, the amounts of carbon dioxide produced at intervals by activated sludge and by activated sludge plus starch are given in Table I. A further indication of hy-

TABLE I.—*Effect of the Addition of Starch to Activated Sludge on CO_2 Production and B.O.D. Removal*

Hrs. Aeration	Sludge CO_2 Mgm.	Sludge Starch CO_2 Mgm.	B.O.D. P.p.m.
0	—	—	110
½	12.6	15.4	95
1	13.4	20.7	60
2	30.6	46.5	45
3	29.0	42.6	30
4	29.6	33.6	30
5	26.4	31.0	25
Total	141.6	189.8	

drolysis is included in this table. The B.O.D. of the liquor of the sludge plus starch was determined after sedimentation at similar intervals, using a complete mineral solution as the dilution medium (5). It will be seen from this table that the B.O.D. of the supernatant decreased with each period of aeration up to 3 hours and that the reduction in B.O.D. was accompanied by an increase in the carbon dioxide production.

The effects of varying sludge concentrations, with the same amount of starch, and of varying starch concentration, with the same quantity of sludge, were next studied. In Fig. 1 is shown the effect of varying

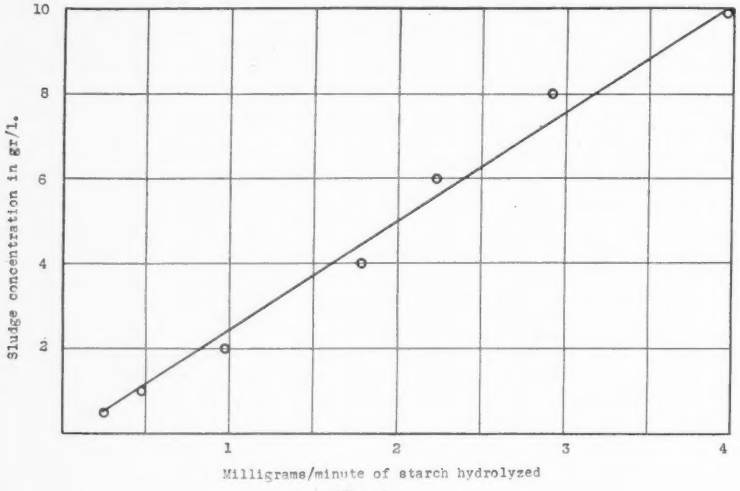

FIG. 1.

sludge concentration on the hydrolysis of 100 p.p.m. starch. The rate of hydrolysis is relatively constant over a concentration range between 500 and 10,000 p.p.m. suspended solids in the sludge. The increase of the starch concentration caused a decrease in the rate of starch hydrolysis from 1.7 mgm. per min. at 50 p.p.m. starch to 0.9 mgm. per min. with 200 p.p.m. starch (table II). The same decrease in the rate of

TABLE II.—*Effect of Increasing Starch Concentration upon the Rate of Starch Hydrolysis*

Starch	Time for Starch to Disappear	Rate
P.p.m.	Minutes	Mgm./Min.
50	30	1.7
100	90	1.1
200	210	0.9
500	420+	—

starch hydrolysis was noted when the starch was added in small increments following the disappearance of the previous dose. The following results were obtained:

1st addition of 50 p.p.m. starch required 30 min.
2nd addition of 50 p.p.m. starch required 90 min.
3rd addition of 50 p.p.m. starch required 150 min.

In the above experiments the role of sewage in the hydrolysis of starch by activated sludge was not considered. The following experiment was conducted to determine this factor. The relative rates of hydrolysis of varying quantities of starch by (1) sewage, (2) sludge and (3) sewage-sludge mixtures are shown in Table III. The sewage

TABLE III.—*Rate of Disappearance of Starch in Sewage, Activated Sludge and Mixture during Aeration*

Starch Mgm.	Time for Disappearance of Starch					
	Sewage [1]		Sludge [2]		Mixtures [3]	
	Minutes	Mgm./Min.	Minutes	Mgm./Min.	Minutes	Mgm./Min.
25	10	2.5	25	1.0	—	
50	25	2.0	70	.7	35	1.4
75	60	1.25	100	.75	—	
100	85	1.18	150	.66	70	1.4
150	190	.80	215	.7	100	1.5
200	340	.60	300	.7	125	1.6
300	420	.71	400	.75	190	1.6
400	—		—		270	1.5
600	—		—		400	1.5

[1] 800 c.c. of sewage.
[2] 1000 c.c. of sludge containing 2000 p.p.m. suspended solids.
[3] 800 c.c. sewage + 200 c.c. of sludge containing 10,000 p.p.m. suspended solids.

had a high rate of starch hydrolysis with low concentrations of starch but the rate decreased from 2.50 mgm. per min. to 0.60 mgm. per min. with increased concentration of starch. The rate of hydrolysis for the sludge was constant at 0.7 mgm. per min. except for the initial high rate of 1.00 mgm. per min. with 25 p.p.m. starch. The sludge-sewage mixtures had also a constant rate of hydrolysis of 1.5 mgm. per min. throughout the range of starch concentrations used. Except for the two high rates of hydrolysis for the sewage with low starch concentrations, the mixtures showed a higher rate of hydrolysis than the sludge or sewage alone. At the higher starch concentrations the rates of hydrolysis for the mixtures were higher than for the two components combined.

An experiment was conducted to determine the specific factors in sewage which aid the hydrolysis of starch by activated sludge. A part of the sewage was boiled to destroy its diastatic activity and a part was Seitz filtered in order to remove the finely dispersed material. Sludge was aerated with untreated sewage, boiled sewage, Seitz filtered sewage, and water, and the time required for 100 p.p.m. starch to disappear was noted as follows:

Sludge P.p.m. Susp. Solids	Liquor	Time for Disappearance Min.
2000	Normal Sewage	15
2000	Boiled Sewage	35
2000	Seitz Filtered Sewage	55
2000	Water	125

The results show that boiled sewage and Seitz filtered sewage aided in the disappearance of the starch even though they contributed no diastase (100° C. destroys all hydrolytic enzymes). The Seitz filtrate also aided in the hydrolysis of starch.

The above results indicate that one of the factors in sewage which promotes the hydrolysis of starch by activated sludge is possibly the nitrogenous material. Therefore peptone and ammonium chloride were substituted for sewage in the hydrolysis of starch by activated sludge. The results, which are given in Table IV, show that ammonia and peptone at least double the rate of starch hydrolysis.

TABLE IV.—*Effect of Food upon Rate of Starch Hydrolysis by Sludge*

Sludge Concentration in Suspended Solids P.p.m.	Starch P.p.m.	Disappearance With Food*		Disappearance Without Food	
		Minutes	Mgm./Min.	Minutes	Mgm./Min.
2000	50	25	2.00	55	0.91
2000	100	55	1.81	105	0.95
2000	200	105	1.91	260	0.77
2000	400	230	1.75	†	
2000	600	340	1.76	†	

* 100 p.p.m. peptone + 25 p.p.m. NH_3 as NH_4Cl.

† Time too long to obtain in one day.

Since the sewage caused a more rapid hydrolysis of starch, it was possible that the increased rate would aid in the rate of B.O.D. removal, and for this reason starch was aerated in the presence of sludge with and without sewage. The results given in Table V show that the starch

TABLE V.—*Effect of Rate of Starch Hydrolysis upon B.O.D. Reduction*

Time of Aeration Hours	Sludge ‡ and Starch *		Sludge ‡ and Sewage and Starch *	
	B.O.D. P.p.m.	Presence of Starch	B.O.D. P.p.m.	Presence of Starch
0	140	+	265	+
½	150	+	175	+
1	130	+	115	+
2	100	+	90	+
2½	—	+	—	—
3	60	+	35	
4	35	+	15	
5	30	+	10	

* 300 mg. starch used.

‡ 2200 p.p.m. suspended solids of sludge.

disappeared in the sludge-sewage mixture within 2½ hours while the starch failed to disappear in the sludge during the 5 hours of the test. In spite of the fact that the B.O.D. of the sludge-starch mixture was lower at first it was higher within 2 hours than that of the sludge-sewage-starch mixture. The rate of B.O.D. removel from the sludge sewage mixture was higher and the B.O.D. finally reached a lower level than the sludge alone.

Discussion

When starch is hydrolyzed by acids or diastase it passes through a number of intermediate stages. A number of dextrins are first produced of which erythro-dextrin gives a red color with iodine, the others being colorless. From each step of dextrin formation a small amount of maltose is produced, the quantity of maltose increasing gradually as the hydrolysis progresses. Maltose in turn is converted into glucose by the action of maltase. Glucose in the presence of bacteria does not accumulate but is utilized by them as a source of energy and carbon.

Several criteria for determining the hydrolysis of starch are thus available. The disappearance of starch can be followed by the iodine test which indicates the hydrolysis to the dextrin stage. When the course of the color change is followed by this method it is noted that the characteristic blue color of starch with iodine gradually changes to purple, red, fading to yellow. These color changes take place in the liquid and at no time could any color be noticed in the sludge or in the liquor surrounding the settled sludge particles.

We have shown an actual increase in glucose during the hydrolysis of starch. That the starch was not quantitatively recovered, as was the case with sugar, was to be expected since in the presence of bacteria the glucose will be continuously utilized by the organisms. The utilization of the products of hydrolysis of starch by bacteria results in the production of CO_2 and the removal of B.O.D. It has been shown that an actual increase in CO_2 production and reduction in B.O.D. takes place during the hydrolysis of starch by activated sludge. Evidence obtained by the use of different criteria indicates that activated sludge cannot only hydrolyze starch but simultaneously removes the products of hydrolysis.

The rate of hydrolysis is influenced by a number of factors. The relative importance of the initial diastase content and further elaboration of diastase through bacterial multiplication should be considered. Sewage has relatively high diastase activity. The source of the diastase in sewage is probably plant and animal products in the form of vegetable matter and feces. The diastatic activity of sewage varies widely depending mainly on the strength of the sewage (2). It may be as high as the diastase activity of the activated sludge. The diastase activity of sewage is primarily determined by the initial diastase content; this is indicated by the decreasing rate of hydrolysis with increasing concentration of starch. In other words, reserve capacity of hydrolysis as influenced by bacterial multiplication is low in sewage.

In addition to the initial diastase content there is an indication that bacterial multiplication and the elaboration of bacterial diastase is an important factor in the rate of hydrolysis. Evidence pointing to this conclusion is as follows: When sewage is added to activated sludge the rate of hydrolysis of starch is increased. Additions of boiled sewage or Seitz filtrate, neither of which contains diastase, give a substantially higher rate of hydrolysis than activated sludge alone. Additions of peptone and ammonium chloride similarly yield a higher rate of hydrolysis of starch by activated sludge.

It becomes apparent that the soluble organic and inorganic materials in the Seitz filtrate exerted a beneficial influence. How are these results to be interpreted? It is obvious that these substances cannot directly increase the rate of catalysis by the diastase originally present. The addition of food substances can influence the hydrolysis of starch in two ways, both of them intimately connected with bacterial multiplication: (1) by the removal of the products of hydrolysis, (2) by increasing the bacterial numbers. The addition of relatively large amounts of starch would represent an unbalanced food condition, resulting in the depletion of the available nitrogen. As the hydrolysis proceeds the utilization of glucose by bacteria would exhaust the available nitrogen supply and would tend to accumulate the products of hydrolysis. Thereafter the rate of hydrolysis would be diminished. In the first place the accumulation of the products of hydrolysis would tend to slow down the reaction, because of the reversible nature of the reaction, secondly further bacterial multiplication and production of diastase would be prevented. The small amounts of ammonia nitrogen and nitrate nitrogen present in activated sludge would be sufficient to allow hydrolysis of small amounts of starch to proceed unabated, but as the amount of starch is increased this retarding effect would be felt due to a deficiency of nitrogen.

The rate of hydrolysis by activated sludge was highest with 25 p.p.m. of starch (1 mgm. per min.). With higher doses the rate drops to 0.7 mgm. per minute. With a sewage-activated sludge mixture the rate of hydrolysis is 1.4 mgm. per minute and does not diminish with higher doses of starch. In the presence of peptone and ammonium chloride the rate of hydrolysis is 2 mgm. per min. for 50 p.p.m. starch and drops to 1.75 mgm. per min. with higher concentrations. If bacterial secretion of diastase is an important factor it should be possible to cultivate a sludge to hydrolyze starch rapidly by repeated additions of starch in the presence of nitrogenous material. Our attempts in this direction have not been successful, mainly because we added only three successive doses of 50 p.p.m. starch. Smit (7) on the other hand, incidental to his studies of conditions favoring bulking of activated sludge, observed that by repeated additions of starch over a longer period the starch digestion took place at an increasing rate. As is well known, hydrolyses and fermentations can be brought about by pure enzyme preparations in the absence of bacteria but these reactions are never as rapid as in the presence of actively growing bacteria.

From the above discussion the best method of treating starch wastes by the activated sludge process would be to mix the wastes with sewage. Because of lack of nitrogen in starch it is doubtful whether starch could be treated without sewage or some other kind of nitrogenous food. The general observation that the best method of treating industrial wastes is in conjunction with sewage seems thus to be borne out. They should naturally be admitted in small and constant amounts and should not have any toxic properties.

It has been shown that the rate of oxidation of sewage sludge mixtures is higher than the oxidation of each component separately. Likewise the hydrolysis of starch proceeds faster in sewage sludge mixtures than either in sewage or sludge separately. Furthermore, not only does the hydrolysis proceed faster in the presence of sewage but the oxidation of the products of hydrolysis and the removal of B.O.D. from the supernatant proceeds faster in the presence of sewage than with activated sludge alone.

The rate of hydrolysis of a substrate is a direct function of the enzyme concentration (1). It is, therefore, not surprising that with increasing sludge concentrations a direct increase was found in the rate of starch disappearance. With increasing sludge concentrations not only is the initial amount of enzyme increased, but more bacteria and food materials are available.

The demonstration of the hydrolytic power of activated sludge for starch has an important bearing on the problem of clarification of sewage by activated sludge. Although starch is not an important normal ingredient of sewage, a mechanism for its hydrolysis is present in activated sludge and can be augmented by proper treatment with starch and sewage. Starch in low concentrations does not impart turbidity and is of little importance in the clarification phase, but it is conceivable that the hydrolysis of other organic materials normally occurring in sewage, may contribute to clarification. Hydrolysis is also necessary to render the colloidal food materials available for bacterial nutrition, and a rapid mechanism of hydrolysis would be prerequisite for biological oxidation of colloidal putrescible material. That this mechanism of hydrolysis is present and proceeds simultaneously with oxidation during early phases of treatment by activated sludge process is apparent for starch. It is evident that during the so-called clarification period the starch is not only hydrolyzed but its product of hydrolysis is removed by oxidation and bacterial proliferation.

Summary

Diastatic activity of sewage, activated sludge and of sewage-activated sludge mixtures were studied by several different methods. Incubation under toluene of a given quantity of starch with different quantities of the test material has been used for a quantitative estimation of the diastatic activity. Results were obtained by determining the smallest amount of the material giving a complete hydrolysis of the starch in 24 hours (negative color with iodine solution). This

method can be used in the estimation of the diastatic activity of the different materials tested. The disappearance of starch added to the aerating mixture and the determination of the minimum time to bring about complete hydrolysis of the starch has been found the more valuable in these studies.

These methods have shown that the hydrolysis of starch is rapid. The rate of hydrolysis depends on the (1) quantity of the starch, (2) the concentration of the sludge, (3) the presence of food (sewage), (4) the presence of adequate air supply and (5) quality of the sludge. Sewage has a diastatic activity equal to, if not higher than, activated sludge. There are variations in diastatic activity of different sewage and activated sludge samples. When sewage is added to activated sludge the diastatic activity of the mixture is increased, because of the diastase and the food contributed by the sewage. The reserve diastatic power of the sewage is lower than of the sludge, as measured by the greater retardation of the rate of hydrolysis when larger amounts of starch are added. The hydrolysis of starch does not result in an accumulation of the products of hydrolysis but these are oxidized as rapidly as they are produced. Thus it has been established, at least with starch, that hydrolysis and oxidation processes take place during the clarification stage, although with starch this may not necessarily result in the removal of turbidity.

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STUDIES ON THE CLARIFICATION STAGE OF THE ACTIVATED SLUDGE PROCESS *

VII. HYDROLYSIS AND BACTERIAL UTILIZATION OF COMPLEX NITROGENOUS MATERIALS BY ACTIVATED SLUDGE

By H. Heukelekian and R. S. Ingols

Associate and Assistant, Division Water and Sewage Research, New Brunswick, N. J.

In an earlier paper of this series it was shown that activated sludge could hydrolyze starch rapidly (2). During the clarification stage starch was not only hydrolyzed but the products of the hydrolysis were removed from the substrate by oxidation. If the sewage contained materials of this nature they could readily be removed by bilogical action of the sludge during the early periods of aeration; but starch is not commonly present in sewage. Is this rapid biological action of sludge specific for starch or is it generally true for complex organic substances of various types? This paper deals with a demonstration of the hydrolytic power of activated sludge for a group of nitrogenous materials of various degrees of complexity. To evaluate the hydrolysis and bacterial utilization of the various nitrogenous materials, different criteria were used such as the production of amino acids, increase in the organic nitrogen content of the pressure filtrate, production of ammonia and nitrate nitrogen and reduction of B.O.D.

Methods

Methods of analysis varied with the different experiments according to the criteria used. In general, suspensions of different nitrogenous materials were aerated with activated sludge and the liquor analyzed for total nitrogen, amino nitrogen, NH_3-N and NO_3-N and B.O.D. Amino nitrogen was determined by the Van Slyke method (5). For pressure filtration a special cell was constructed from brass tubing (1½ in. diameter) fitted with a cap on top and a union on the bottom. The cap was fitted with a tire valve for introducing and maintaining the pressure. The union was altered so that rubber gaskets and a brass plate could be inserted. The brass plate was drilled with ⅛ in. holes in the center and then covered with a fine mesh screen which was soldered to the rim of the plate. The brass plate and screen acted as support for the parchment membrane used as the filtering medium.

Results

To demonstrate the hydrolysis of gelatin, a 5000 p.p.m. suspension of gelatin was mixed with activated sludge (2000 p.p.m. suspended solids) and allowed to stand for 20 hours in the presence of formaldehyde. This antiseptic was used to prevent the biological assimilation of the products of hydrolysis. Amino nitrogen was determined in the

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supernatant by the Van Slyke method (5). The results were as follows:

1. Amino nitrogen obtainable from the complete hydrolysis of 5000 p.p.m. gelatin ..... 525 p.p.m.
2. Amino nitrogen obtained after 20 hours of hydrolysis with activated sludge ..... 150 p.p.m.
3. Percentage of the total amino nitrogen obtained 28.5
4. Gelatin hydrolyzed in 20 hours ..... 1425 p.p.m.
5. Gelatin hydrolyzed per hour ..... 71 p.p.m.

The literature contains evidence (1) that 5000 p.p.m. of gelatin will, on complete hydrolysis, liberate 525 p.p.m. of amino nitrogen. (Calculated on the basis of 70 per cent of the 750 p.p.m. of total nitrogen in the gelatin.) A total of 150 p.p.m. of amino nitrogen was actually recovered after 20 hours of contact with the activated sludge. This corresponds to 28.5 per cent of the total possible amino nitrogen in the gelatin. On this basis 1425 p.p.m. of the gelatin was completely hydrolyzed in 20 hours or about 70 p.p.m. per hour. Actually all of the gelatin was partially broken down to polypeptides with the liberation of only a few individual amino acids.

A study was conducted to determine whether the aeration of an albumin suspension was activated sludge will increase the filtrable nitrogen fraction. An albumin suspension of 250 p.p.m. was made and the total nitrogen in the suspension determined. The suspension was then passed through a parchment membrane in the pressure filter and the total and NH_3-N in the filtrate determined. Another portion of the same albumin suspension was mixed with activated sludge, settled immediately after mixing, and the total and ammonia nitrogen in the supernatant determined. A portion of the supernatant was pressure filtered and total and ammonia nitrogen determined on the filtrate. Similar determinations were made on the supernatant and pressure filtrate after 2 hours' aeration with activated sludge. The results are given in Table I.

TABLE I.—*Increase of Organic Nitrogen in Pressure Filtrate by Aerating an Albumin Suspension* [1] *with Activated Sludge*

	Total N P.p.m.	NH_3–N P.p.m.	Organic N P.p.m.	Per Cent of the Organic N in Pressure Filter
1. Albumin suspension	25.0	1.7	23.3	
2. Albumin suspension pressure filtered	4.9	1.7	3.2	13.8
3. Mixed supernatant [2]	25.0	7.0	18.0	—
4. Mixed supernatant pressure filtered	9.6	7.0	2.6	14.4
5. Mixed supernatant after 2 hrs. aeration	15.0	1.1	13.9	—
6. Mixed supernatant after 2 hrs. pressure filtered.	6.9	1.1	5.8	41.5

[1] Albumin suspension 250 p.p.m.

[2] Albumin suspension 250 p.p.m. + activated sludge.

Only 13.8 per cent of the organic nitrogen in the original albumin suspension was filterable through parchment. The same amount of

total nitrogen was recovered in the supernatant immediately after mixing with activated sludge but the ammonia nitrogen of the supernatant was greater, due to the ammonia nitrogen of the sludge, giving a slightly lower organic nitrogen content than the original albumin suspension. The pressure filtrate also had a higher *total* nitrogen content than the original filtrate of the albumin suspension but when corrected for the larger amount of *ammonia* nitrogen, the *organic* nitrogen in the pressure filtrate immediately after mixing was slightly lower than that of the original pressure filtered albumin suspension. The total nitrogen as well as organic nitrogen of the supernatant after 2 hours' aeration had decreased considerably. At the beginning of the aeration period there was 15.4 p.p.m. non-filtrable organic nitrogen in the supernatant; at the end, there was 8.1 p.p.m. or a decrease of 7.3 p.p.m., while in the filtrate after 2 hours' aeration the quantity of organic nitrogen had increased 3.2 p.p.m. The 2.6 p.p.m. of filtrable organic nitrogen was only 14.4 per cent of the total organic nitrogen but after the aeration it was 41.5 per cent of the organic nitrogen.

An experiment was designed to correlate the degree of complexity of proteins with the rate of ammonia and nitrate production. Albumin, gelatin and peptone were selected as nitrogenous materials of different degrees of complexity. A portion of albumin was previously subjected to enzymic hydrolysis as follows: an albumin suspension of 0.5 gram in 100 ml. was prepared, the pH adjusted to 8.5, and 0.1 gram of trypsin added. The suspension was covered with toluene to prevent bacterial action and incubated at 37° C. for one week. At the end of this period hydrolysis was about 50 per cent complete, as indicated by the amino nitrogen-total nitrogen ratio. The toluene was driven off by aeration. The tryptic digest thus prepared and the other nitrogenous materials were added to activated sludge to give a final concentration of 250 p.p.m. of nitrogenous materials. The suspended solids in the activated sludge had a concentration of 2000 p.p.m. A control was used, with similar concentration of activated sludge but without any addition of nitrogenous material. The various mixtures were aerated and samples drawn at different intervals. The samples were centrifuged and ammonia and nitrate determinations made on the supernatant. The results are given in Table II.

Very little ammonia or nitrate were present in the control. The small initial amount of ammonia disappeared rapidly and was recovered as nitrate. The aeration of albumin with activated sludge for a period of 5 hours did not result in an increase in the ammonia or nitrate content. However, the albumin which had been subjected previously to tryptic hydrolysis showed a rapid increase in ammonia during the first hour's aeration with activated sludge, reaching a maximum in two hours. After two hours, nitrification tended to prevent a further increase in ammonia level, although there was a continued production of ammonia. With gelatin, ammonia production was lower than with the tryptic digest during the first three hours but was decidedly higher than in the test with albumin. Ammonia production

TABLE II.—*Production of Ammonia and Nitrate Nitrogen from Nitrogenous Materials by Aeration with Activated Sludge*

Aeration.	Control		Albumin		Tryptic Digest		Gelatin		Peptone	
	NH_3-N	NO_3-N	NH_3-N	NO_3-N	NH_3-N	NO_3-N	NH_3-N	NO_3-N	NH_3-N	NO_3-N
Hours	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
0	.4	0	.35	0	.35	0	.35	0	.35	0
1	0	0	<0.2	.2	4.0	.8	0.8	.8	2.3	0
2	0	.2	<0.2	0	5.0	3.6	1.2	3.6	2.6	2.8
3	0	.2	<0.2	0	5.0	4.8	2.4	5.2	4.5	4.8
4	0	.3	<0.2	0	4.5	7.2	4.0	5.2	4.5	4.0
5	0	.4	<0.2	0	4.0	7.2	5.0	4.8	5.0	7.2

from peptone was intermediate between gelatin and tryptic digest. In Fig. 1 the sum of the ammonia and nitrate nitrogen produced from these different materials is represented graphically.

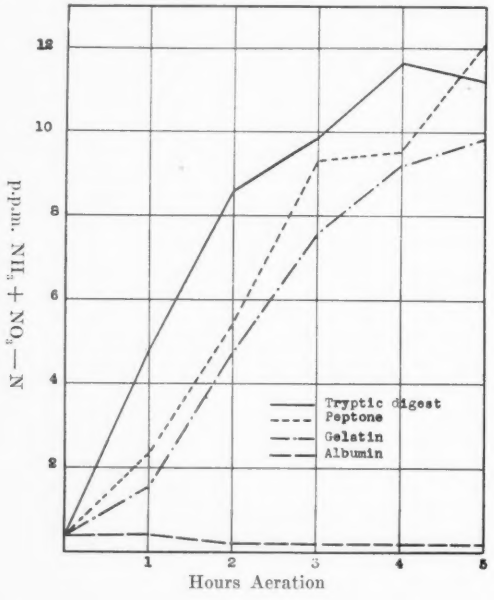

FIG. 1.

That the B.O.D. removal from these materials is of the same order as the ammonia production is indicated in Table III. The nitrogenous materials were added in 250 p.p.m. concentration to an activated sludge containing 2000 p.p.m. suspended solids. The different mixtures were aerated for a period of five hours. At intervals samples were taken and centrifuged. Five-day B.O.D. determinations were made on the supernatant using the mineral dilution water recommended by Lea and Nichols (3). The results showed that the highest rate of B.O.D. re-

TABLE III.—*B.O.D. Removal of Nitrogenous Materials by Aeration with Activated Sludge*

	Hours Aeration						
	0	½	1	2	3	4	5
	Parts Per Million						
Albumin	175	155	145	100	100	105	90
Tryptic digest of albumin	165	175	110	75	20	20	20
Gelatin	165	185	175	115	90	75	65
Peptone	205	185	150	80	70	55	45

moval was obtained with the tryptic digest of albumin and the lowest from the albumin. The B.O.D. removal from peptone was more rapid than from gelatin. The removal of the various nitrogenous materials was of the same order as that obtained by using ammonia production as the criterion.

In order to study the hydrolysis of nitrogenous materials in sewage by activated sludge it was necessary to determine how much of these materials are present in normal domestic sewage. A sample of cotton-filtered domestic sewage was successively filtered through Seitz and pressure membrane filters. Ammonia and total nitrogen were determined on the filtrates and in the residue on the filters. The results were as follows:

	NH_3-N P.p.m.	Total N P.p.m.	Organic N P.p.m.
Cotton Filtered Sewage	21.8	37.5	15.7
Seitz Filtrate	20.0	31.8	11.8
Resid ue on Seitz Filter	—	4.1	4.1
Pressure Filtrate	18.7	32.0	13.3
Residue on Pressure Filter	—	0.0	0.0

The greatest percentage of nitrogen in sewage was in the form of ammonia. Most of the organic nitrogen was in such a state of subdivision that it passed through a Seitz filter and also a membrane filter. Only 4.1 p.p.m. or 27 per cent of the total organic nitrogen in the sewage was retained on the Seitz filter. Bacterial cells or other nitrogenous materials of similar size as bacterial cells would be retained on the Seitz filter. The failure of the membrane filter to remove organic nitrogen would indicate that nitrogenous material of true colloidal size was absent in the sewage. In sewage, therefore, most of the organic nitrogen is in a diffusible form such as amino acids and only a small portion in colloidal aggregates such as in bacterial protoplasm. The study of the rate of hydrolysis of this small amount of nitrogenous material retained by the Seitz filter would be extremely difficult because

of the presence of such large amounts of ammonia and organic nitrogen in a soluble form.

Discussion

Proteins are characterized by the large size of their molecules. This fact prevents their direct assimilation by any organism. Bacteria must hydrolyze the proteins by means of extra-cellular enzymes. The hydrolysis goes through a number of different stages. Each cleavage product is less complex and smaller in size. Some of these products formed are proteoses, peptones and peptides, all of which are too large to be directly assimilated. Further hydrolysis of these substances yields amino acids. Amino acids serve as one source of energy to bacteria which break them down to ammonia, carbon dioxide and water. The ammonia produced from the deaminization of amino acids may be used as the source of nitrogen for the synthesis of new protoplasm in the presence of an adequate source of carbon, or the ammonia may be used for energy transformations by the nitrifying bacteria.

In evaluating the hydrolytic power of activated sludge for a protein a number of criteria can be used, none of which by itself gives the complete picture. For instance, if amino acid production is used as an index of hydrolysis a low value may be obtained due to the utilization of the amino acids. Similarly the possibility of the reassimilation and the oxidation of the ammonia should be borne in mind when the ammonia production is being used as an index of protein hydrolysis. It is difficult to separate one reaction from the other and stop it at a desired end point, because these reactions proceed more or less simultaneously. Nevertheless, by the use of these various criteria certain indications have been obtained.

A large increase in the amino nitrogen was obtained from the hydrolysis of gelatin by activated sludge in the presence of formaldehyde. This antiseptic was used because it does not effect the proteolytic enzymes materially but it effectively prevents the bacterial utilization of the amino acids, thus allowing the amino acids, produced during the hydrolysis, to accumulate. The rate of hydrolysis as determined by the production of amino nitrogen under these conditions was quite appreciable (70 p.p.m. gelatin hydrolyzed per hour).

Filtering membranes may be used to separate particles of different sizes in a similar way to sieving sand. Parchment paper is frequently chosen as a membrane to differentiate between colloids and true solutions, but this differentiation is not absolute. Albumin, which has a larger molecule than gelatin, will not go through a parchment membrane as readily as gelatin. Hydrolysis resulting in smaller size particles will increase the amount of organic nitrogen going through the membrane. Evidence gathered from this method of study indicates that albumen is hydrolyzed by activated sludge during two hours' aeration, sufficiently to increase the organic nitrogen in the membrane filtrate. Since antiseptics were not used in this experiment to prevent the bacterial utilization of the products of hydrolysis the values obtained are lower than the total amount actually hydrolyzed.

Using the production of ammonia as an index of hydrolysis of different nitrogenous substances, albumin appears to be the most resistant. When albumin is previously subjected to a tryptic hydrolysis and subsequently mixed with sludge and aerated, it is rapidly utilized, as indicated by ammonia production. After one hour, ammonia produced from the digest increased from 0.35 to 4.0 p.p.m. Thereafter further increase was slow because part of the ammonia liberated from the decomposition of the amino acids was oxidized to nitrates. It is therefore possible to convert within two hours a part of the nitrogen in the original digest to nitrates. Since this is the case it seems justifiable to add the nitrate nitrogen to the ammonia nitrogen in estimating the extent of hydrolysis. Even then, part of the original nitrogen which might be utilized by bacteria after hydrolysis will not have been taken into account, for part of the hydrolyzed protein will not reach the ammonia stage but will be used directly in building protoplasm.

Gelatin was hydrolyzed more rapidly than albumin but not so rapidly as the tryptic digest or peptone. The hydrolysis as indicated by the sum of the ammonia and nitrate nitrogens produced was most rapid with the tryptic digest followed by peptone and then gelatin. In the tryptic digest the hydrolysis of the protein had gone further than the peptone stage, possibly to peptides and amino acids.

The evidence indicates that the rate of ammonia production varies inversely with the degree of complexity and directly with the degree of hydrolysis of the different materials employed.

A similar conclusion may be reached by studying the B.O.D. removal from these substances by activated sludge. The tryptic digest gave not only the most rapid rate of B.O.D. removals but also the lowest B.O.D. values. This was closely followed by B.O.D. removal from peptone. The initial B.O.D. with peptone was higher and therefore the values with aeration did not decrease to so low a level as with the tryptic digest. Gelatin, after albumin, permitted the lowest rate of B.O.D. removal.

The results obtained show that nitrogenous materials are hydrolyzed by activated sludge and that the rate of hydrolysis depends on the complexity of the molecule or the stage of hydrolysis. Amino acids, ammonia and nitrate nitrogen may be obtained from some of these materials with 1 to 2 hours of aeration with activated sludge. Activated sludge must therefore contain the necessary mechanism for the hydrolysis of nitrogenous materials. This mechanism operates simultaneously with clarification. Whether there is any causal relation between hydrolysis and clarification, it seems significant that all these biological reactions proceed rapidly during the initial stage of aeration.

It is essential that a hydrolytic mechanism be present in activated sludge if the purification and removal of oxygen consuming materials is to be attributed to bacterial action. It is significant, therefore, that not only hydrolysis, as indicated by the production of ammonia, but also the removal of oxygen-consuming materials, increases in the ex-

pected manner according to the decreasing order of complexity, the increasing stage of hydrolysis of the materials, or their availability for bacterial utilization.

According to Traube's rule (4) the adsorption of members of an homologous series from aqueous solutions increases with increasing molecular weight. The results obtained with nitrogenous materials of varying molecular weight show that the lower the molecular weight the greater the rate of bacterial utilization. Adsorption may thus play an increasingly important role with larger molecules while direct bacterial utilization may be the predominating factor with smaller molecules.

The finely divided solids of sewage contain a larger proportion of organic nitrogenous materials in the small molecular size, as revealed by fractional filtration through a Seitz filter and a parchment membrane. A small portion of its organic nitrogen in cotton-filtered sewage is retained by the Seitz pads. This fraction might consist of the protoplasmic material in the bacterial cells or of colloidal aggregates. Proteins do not constitute an important part of the nitrogenous materials in the finely dispersed portion of the sewage. Proteins are associated with the larger solid particles which on hydrolysis liberate into the liquid portion organic nitrogenous materials of smaller molecular size. An activated sludge plant treating settled sewage does not deal with large amounts of non-hydrolyzed organic nitrogen, but with non-settled sewage and with sewage containing packinghouse or dairy wastes, hydrolysis of proteins in the activated sludge process may be an important factor.

Summary

Evidence has been produced which indicates the presence of proteolytic enzymes in activated sludge. The hydrolysis of nitrogenous materials has been followed using the production of amino acids, ammonia, nitrates, increase in the organic nitrogen in a pressure filtrate, and the removal of B.O.D. The amino acid production from gelatin in contact with activated sludge, in the presence of formalin, is appreciable. Albumin, though more resistant to hydrolysis, gives an appreciable increase of organic nitrogen in the filtrate from a parchment membrane after two hours' aeration with activated sludge. Ammonia production from albumin aerated in the presence of activated sludge is very low, but when the albumin is previously subjected to tryptic hydrolysis, ammonia is rapidly produced by aeration with activated sludge. The ammonia nitrogen does not increase appreciably because it is oxidized to nitrate. Gelatin is hydrolyzed more readily than albumin and less readily than a tryptic digest of albumin. Peptone occupies an intermediate position between the tryptic digest and gelatin.

Similar results are obtained with these materials using B.O.D. removals as a criterion. The order of biological action (hydrolysis and reduction of B.O.D) varies inversely with the complexity of the molecule and directly with the stage of hydrolysis of the original materials. The hydrolysis and the removal of products of hydrolysis by oxidation

of the nitrogenous materials is rapid during the initial period of aeration with activated sludge. Dispersed material in domestic sewage contains little colloidal nitrogenous material of a non-hydrolyzed nature. Most organic nitrogen in sewage is in the form of colloidal aggregates such as bacterial cells removable by a Seitz filter.

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MEASURES OF NATURAL OXIDATION IN POLLUTED STREAMS

IV. EFFECT OF SEWAGE ON ATMOSPHERIC REAERATION RATES UNDER STREAM FLOW CONDITIONS

By Robert W. Kehr

Passed Assistant Sanitary Engineer, Stream Pollution Investigations, U. S. Public Health Service, Cincinnati, Ohio

In the third paper of this series,[1] the rates of atmospheric reaeration of deaerated tap water free of oxygen demand were determined under a wide range of conditions in a 1,080-ft. flume and in a continuous-flow recirculation channel 6 in. wide, 18 in. deep and 58.4 ft. long. In continuing the study of natural oxidation in polluted streams, a number of experiments were made to determine the rate of bio-chemical oxidation of sewage and sewage sludge deposits in the recirculation channel under stream flow conditions. The amounts of oxidation occurring in the channel during various periods of time were computed from the observed oxygen saturation deficiencies by means of the previously determined rates of absorption of atmospheric oxygen into unmodified tap water streams flowing in the same channel under identical conditions of depth and flow, these rates being corrected to the observed oxygen deficiencies. The total amounts of oxygen thus computed as being absorbed by the sewage and sludge deposits during these experiments greatly exceeded, however, the corresponding amounts accounted for in terms of measured progressive reductions in their total biochemical oxygen demand. In an attempt to determine the cause of this discrepancy, an extended series of measurements has been made of the reaeration of tap water admixed with various amounts of sewage and sewage sludge. The results of these measurements, somewhat unexpected in their general trend, have been considered to be of sufficient interest to warrant separate presentation in the paper which follows.

Although no references have been found in the literature giving extensive quantitative data on the effect of sewage on rates of solution of oxygen into water, several authors have noted that oxygen is absorbed more slowly into sewage than into "clean water" under comparable conditions. Kessener and Ribbius [2] conclude, in regard to activated sludge aeration systems, that "diffused air aeration is more unfavorably influenced by colloidal organic matter in sewage than surface aeration. This fact must still be confirmed by a series of aeration experiments with sterilized sewage." Watson [3] found that 2.2 p.p.m. of oxygen were absorbed into strong sewage from a fixed quantity of air bubbled through it, whereas 3.9 p.p.m. were absorbed under the same conditions by a "good sparkling final effluent." Data published by Parsons and Wilson [4] indicate that when air is bubbled through unsterilized sewage there is a definite lowering of the rate of increase of dissolved oxygen at a pH of 8.0, due to biochemical action,

but no consistent effect at a pH of 4.0 or 10.0, at which pH levels biochemical oxidation is probably negligible for short intervals of time after the beginning of the experiment.

As the reserve oxygen content of streams always tends to become considerably reduced below major sources of pollution, it is important that the extent to which the presence of sewage in such streams may tend to modify their rates of recovery of oxygen from the atmosphere be definitely known, if possible, under various conditions of flow and sewage concentration. The results of the experiments herein described have afforded consistent evidence on this point. They indicate, in brief, that the admixture of sewage or sewage sludge with fresh water tends to retard the rate of atmospheric reaeration under stream flow conditions except in practically quiescent waters, where the measured difference was comparatively small. A series of additional experimental results indicated that similar retarding effects in the rates of oxygen absorption at higher velocities were produced by certain substances normally present in sewage, such as urine, soaps and oil films.

Experimental Methods

In general, the procedure followed in the experiments was: (1) to place in the recirculation channel * the deaerated mixture to be used, (2) inhibit biochemical oxidation, then (3) recirculate at a constant speed and measure the rate of increase in dissolved oxygen. In most of the experiments the temperature did not vary widely from 20° C. The rate of increase of oxygen in the mixture under consideration was compared with that of tap water at the same temperature, flow velocity, and degree of oxygen saturation, after correcting for variations in barometric pressure.

Two general methods were used to deoxygenate the water. The first was biochemical deaeration, wherein the mixture was permitted to stand quiescent for a time and biochemical action allowed to proceed until the dissolved oxygen dropped approximately to zero. With this procedure, mixtures of 25 per cent or more of sewage in tap water usually became deaerated satisfactorily overnight. This method was not effective with low percentage mixtures of sewage in water, or unseeded mixtures other than sludge and sewage. When anaerobic biochemical action prevailed for any appreciable time, an "immediate" oxygen demand was noted, as indicated by the greater length of time necessary for dissolved oxygen to appear in the deaerated mixture being reirculated. That the satisfaction of this rapid demand was substantially complete before dissolved oxygen appeared could be determined from the rate of increase of dissolved oxygen in the mixture. This was proportional to the oxygen saturation deficiency, with no appreciable lag after oxygen once appeared in the tank.

In the second method, sodium sulfite was added to the tap water and, after a short period of mixing to complete the chemical reaction, the sewage or other substance was added, the excess sulfite slightly over-

* For description, see *This Journal*, **8**, 294 (March, 1936).

neutralized with chlorine solution, and the pH corrected by adding sodium hydroxide. With sewage mixtures of 10 per cent or above in tap water, it was not possible to deaerate the mixture directly, as the presence of sewage interfered with the reaction between sodium sulfite and the dissolved oxygen. One hundred p.p.m. of sodium sulfite was sufficient to deoxygenate tap water completely in a very short time. To neutralize the excess of sulfite, a chlorine solution of 3,000 to 6,000 p.p.m. was slowly siphoned into the recirculating mixture until a starch-iodide spot test showed distinctly that free chlorine was present, the excess usually ranging in concentration between 5 and 25 p.p.m. In making the Winkler test for dissolved oxygen in these chlorinated mixtures, a correction was applied for the free chlorine present by titrating an acidified duplicate sample with standard thiosulfate solution in the presence of starch-iodide indicator. This correction was deducted from the result of the regular Winkler method titration, which would include both dissolved oxygen and the free chlorine present. As the same method of deaeration was used in determining rates of absorption of oxygen into tap water, these tap water rates, taken from the preceding paper of this series,[1] and corrected to the observed water temperatures, have been used in the present paper as a standard of reference in determining the effect of sewage on rates of dissolved oxygen absorption.

With the sulfite-chlorine method of deaeration, as above described, the excess of chlorine present was sufficient to arrest biologic action during the period of a test and in some experiments chlorine was added for this purpose when the mixture was deaerated biochemically. Another method of arresting biologic action was to lower the pH value to approximately 3. Comparable rates of reaeration were obtained in check experiments using these various methods of deaerating and arresting biologic action. The effectiveness of the methods followed in arresting biologic action was repeatedly checked by aerating a sample of the tank mixture and making dissolved oxygen determinations at various intervals of time on portions stored at the channel temperature in sealed bottles. The use of low pH to check biologic action was not effective for time intervals over 5 or 6 hours, especially when the concentration of sewage in the mixture was 25 per cent or more. In one experiment the pH was shifted from 3.6 to 11.6 by rapidly adding sodium hydroxide during the run. This produced a slight effect, the rate of reaeration being lowered about 5 per cent during the latter half of the run.

The method used in determining dissolved oxygen was the original Winkler method with a short period of alkalization, as recommended by Theriault [5] for the determination of dissolved oxygen in the presence of large amounts of relatively stable forms of organic matter. A later comparative study of results obtained by various modifications of the Winkler test, including the short-alkalinization modification, has been carried out by W. A. Moore of this station, using as a standard of comparison parallel results obtained by a more exact gasometric method.

The results of this study, to be presented separately by Mr. Moore, have indicated that although the particular modification used in connection with these experiments gives low results with a degree of error increasing progressively with the concentration of sewage or sewage sludge in tap water, the mean error observed did not exceed about 3 per cent for sewage concentrations up to 25 per cent, or for the B.O.D. equivalents of these concentrations in the presence of sewage sludge. As this low percentage of error was well within the combined error of the observations, it was considered that all of the experimental results obtained in sewage concentrations not exceeding 25 per cent, as well as in equivalent sludge concentrations, were significant without correction, and these results constitute the base data of the present paper. Although the results obtained in higher concentrations, both of sewage and of sewage sludge, were quite consistent in their general trend with those observed in the concentrations ranging below 25 per cent, they have been excluded from these data as being open to possible question as to their experimental accuracy.

Analytical Treatment of Data

The method of analytical treatment of the experimental data used in this study was the same as the method described in the preceding paper of this series.[1] Each observation of dissolved oxygen was expressed in terms of the percentage of saturation deficiency at that temperature and barometric pressure and the constant (k_2) obtained on an hourly basis by plotting the saturation deficiency against time in hours on semilogarithmic paper.* The equivalent rate of reaeration in grams per square meter per day at zero saturation (r_0), was obtained from the (k_2) value by means of the relationship $r_0 = -2.3\, k_2 D_0$,† in which (D_0) was the dissolved oxygen saturation value in p.p.m. at the observed temperature and (r_0) was converted from p.p.m. per hour to terms of grams per square meter per day by multiplying it by the factor 152 (a constant for the particular conditions of these experiments).

Effect of Temperature

A large proportion of the reaeration experiments were made at temperatures approximating 20° C., but during the summer it was not possible to keep the temperature down to this level. There was not a sufficient number of runs at higher temperatures to obtain temperature correction factors for rates of reaeration as observed in the various mixtures of tap water with sewage or sewage sludge. In order to make the rates observed at temperatures other than 20° C. comparable with those previously established for tap water alone at that temperature, it was necessary, therefore, to correct these tap water rates to their equivalents at the observed temperature for each experiment, using the temperature correction factor previously derived from the extensive series of tap water measurements described in the third paper of this series.[1] On the basis of this factor, the rate of surface reaera-

* For illustrative example see *This Journal*, **8**, 298 (Fig. 3), (March, 1936).
† See equation (4), *This Journal* **7**, 537 (1935).

tion (r_0) at 20° C. has been corrected in the tables which follow to the temperature of observation in accordance with the formula:

$$r_0\ (T\ ^\circ\text{C.}) = r_0\ (20^\circ\ \text{C.}) \times 1.016^{(T-20)},$$

which in effect denotes an increase of 1.6 per cent in the rate (r_0) for each successive degree in temperature.

Effect of Varying Percentages of Sewage on the Reaeration Rate

A flow velocity of approximately 24 feet per minute in the channel was arbitrarily chosen for the initial experiments and was the one most frequently used throughout the entire series.

In Fig. 1 are shown the rates of reaeration, expressed as percentages of the corresponding tap water rates, obtained when various per-

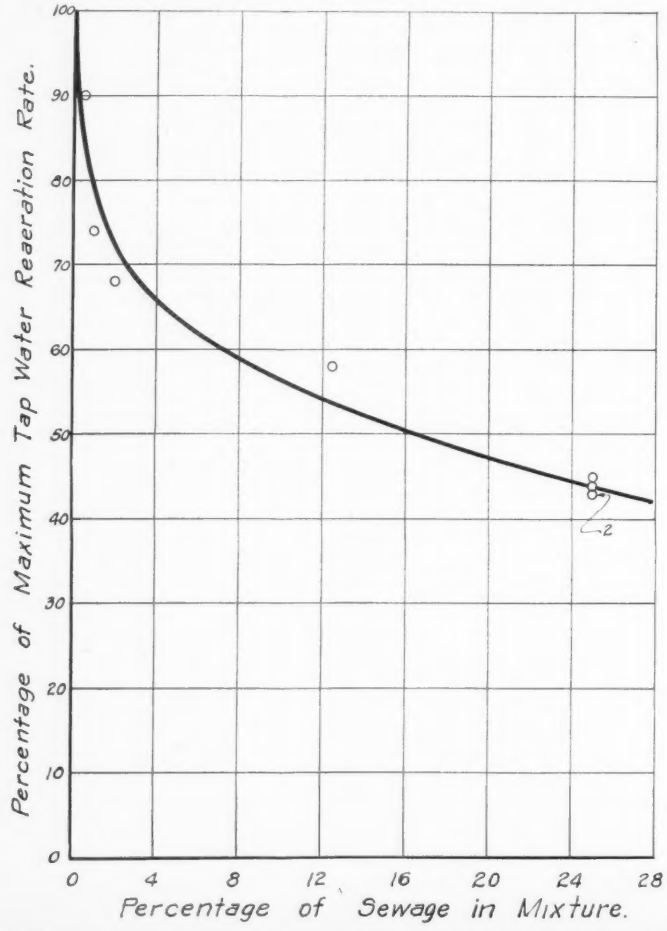

Fig. 1.—Percentage of tap water r_0 obtained when tap water was admixed with sewage.

TABLE I.—*Results of Eight Reaeration Measurements with Varying Concentrations of Sewage in Tap Water and Approximately the Same Velocities of Flow*

Sewage Concentration, Per Cent	Water Temperature, °C.	Velocity of Flow, Ft./Min.	Reaeration Rate[2] (r_0) at Obs'd Temp., Gms./Sq. Meter/Day		Per Cent of Tap Water Rate Observed	
			Observed Rate	Tap Water Rate	Each Exp't	Mean for Conc'n
0.5	20.3	22.2	22.8	25.2	90	90
1	20.2	22.2	18.7	25.2	74	74
2	20.0	22.0	17.0	25.0	68	68
12.5	19.9	21.2	13.9	24.0	58	58
25	20.0	21.6	10.6	24.4	43	
25	19.6	21.6[1]	10.8	24.4	44	44
25	21.7	21.6[1]	11.2	25.1	45	
25	20.1	21.6[1]	10.6	24.4	43	

[1] Not measured, but assumed as equal to measured velocity with same sewage concentration and paddle speed.

[2] r_0 = initial rate at zero oxygen saturation.

TABLE II.—*Results of Experiments with Four Different Concentrations of Sewage in Tap Water, Flowing at Velocities in Four Different Ranges*

Sewage Concentration, Per Cent	Water Temperature, °C.	Velocity of Flow, Ft./Min.	Reaeration Rate (r_0) at Obs'd Temp., Gms./Sq. Meter/Day		Per Cent of Tap Water Rate Observed
			Observed Rate	Tap Water Rate	
A. Velocity = 4.7–5.3 ft. per minute.					
0.5	25.7	5.0	3.3	3.6	92
2	25.2	4.7	2.9	3.2	90
10	25.8	5.3	2.9	3.8	76
25	25.2	5.2	2.8	3.9	72
B. Velocity = 9.8–11.3 ft. per minute.					
0.5	25.6	10.7	6.6	10.4	64
2	25.2	9.9	5.4	9.8	55
10	25.6	11.3	5.2	11.4	46
25	25.5	9.8	5.1	9.7	52
C. Velocity = 20.5–23.1 ft. per minute.					
0.5	25.5	21.4	17.6	25.8	68
2	25.2	20.9	15.9	25.0	64
10	25.3	20.5	10.8	24.8	44
25	26.0	23.1	9.7	28.5	34
D. Velocity = 28.3–29.3 ft. per minute.					
10	25.3	29.3	15.9	37.8	42
25	26.1	28.3	13.4	36.3	37

centages of sewage were mixed with tap water and recirculated at a velocity of approximately 24 feet per minute in the recirculation channel. The data on which this plot is based are given in Table I. It is interesting to note how markedly the lower concentrations of sewage affected the tap water reaeration rate at this velocity. With 1 per cent of sewage concentration the reaeration rate observed was only 74 per

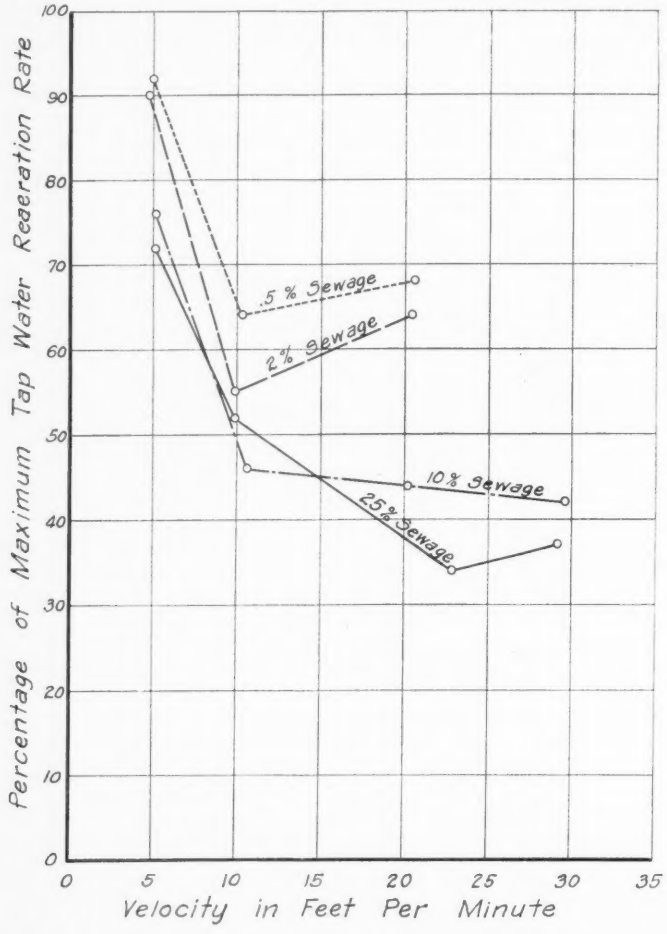

FIG. 2.—Effect of velocity of recirculation on reaeration rates of sewage-tap water mixtures.

cent of the corresponding rate in tap water, and with 25 per cent concentration, was less than half the corresponding tap water rate.

The marked lowering of the reaeration rate did not, however, hold constant throughout a wide range of velocities, as is apparent in Table II and Fig. 2, showing the percentages of the corresponding tap water reaeration rates obtained with four different concentrations of sewage

in tap water and at velocities of flow falling within four distinct ranges. Each series of observations with a given sewage concentration was obtained from one run by varying the velocity during that run. The marked retarding effect on the surface reaeration rate observed at higher velocities tended to be greatly diminished at velocities of 3 to 5 ft. per min., in which range there was a definite break in the linear re-

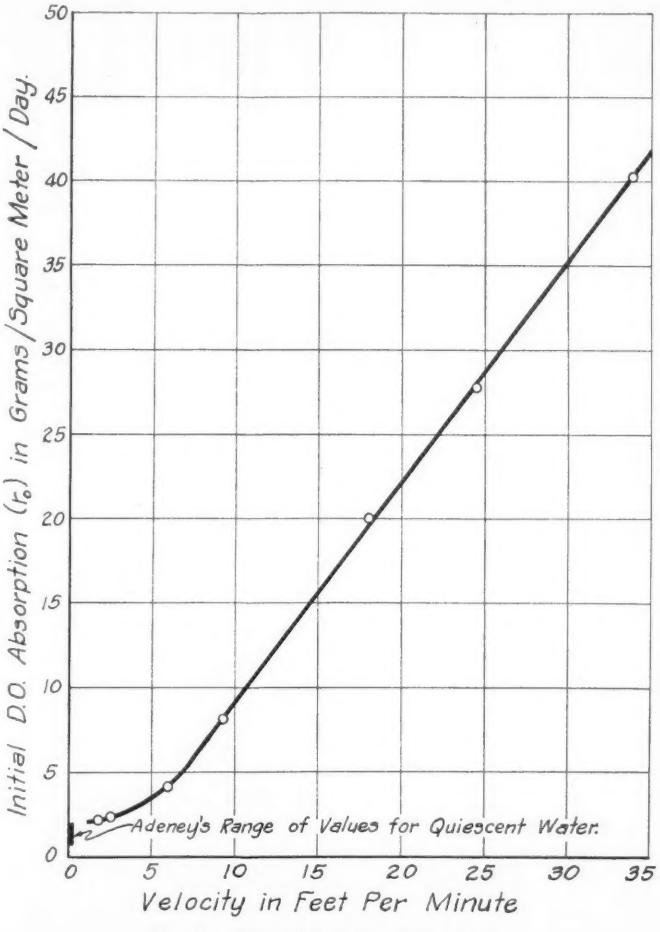

FIG. 3.—Reaeration rates of tap water.

lationship between velocity and rate of reaeration for tap water, as can be seen in Fig. 3, and also between laminar and turbulent flow, as shown in the third paper [1] of this series. The data plotted in Fig. 3, except for the lowest two points on the curve, are taken from Table VIII of the preceding paper [1] just noted. The lowest two points, corresponding to velocities of 1.9 ft. per min. and 2.6 ft. per min., gave rates of reaeration (r_o) at zero saturation of 2.2 and 2.3 gr. per sq. m. per day,

respectively. These rates correspond approximately to the upper limit of atmospheric reaeration in quiescent distilled water, according to data given by Adeney,[6] from which it is computed that the rate of oxygen absorption (r_0) at zero saturation would vary from 0.65 to 1.9 gr. per sq. m. per day, depending upon the humidity in the atmosphere. It should be borne in mind, however, that the point at which turbulence begins seriously to affect the reaeration rates would not necessarily be the approximately 4 ft. per min. velocity as shown on the curve in Fig. 3, as this point would in all probability depend upon the physical conditions inducing turbulence. Velocity in the experimental recirculation channel was induced by revolving boat propellers, and the channel contained five 180° bends, each of which created some turbulence at lower velocities. The net effect of these paddles and the 180° bends probably would cause, at a given velocity, more turbulence in the recirculation channel than in a smooth, straight channel with flow induced by gravity.

That the presence of sewage sludge in tap water produces retarding effects on reaeration similar to those of sewage is shown by the data included in Table III, which is a summary of results obtained from a

TABLE III.—*Results of Experiments with Various Concentrations of Sewage Sludge Deposit in Tap Water, Flowing at Velocities in Three Different Ranges*

Sludge Concentration in Channel, P.p.m. Dry Solids	Water Temperature, °C.	Velocity of Flow, Ft./Min.	Reaeration Rate (r_0) at Obs'd Temp., Gms./Sq. Meter/Day		Per Cent of Tap Water Rate Observed	
			Observed Rate	Tap Water Rate	Each Experiment	Mean for Velocity Range
A. Velocity = 4.2–5.0 ft./minute.						
13	23.9	4.4	2.8	3.3	85	
37	23.9	4.2	2.8	3.2	88	86
79	24.7	5.0	3.2	3.8	84	
B. Velocity = 7.6–9.9 ft./minute.						
13	23.9	8.9	4.7	8.3	57	
37	23.3	7.6	4.2	6.5	65	59
79	23.8	9.9	5.2	9.4	55	
C. Velocity = 13.8–19.6 ft./minute.						
19	20.5	19.6	12.5	21.8	57	
38	20.3	17.0	10.0	18.1	55	58
114	21.0	13.8	8.7	14.2	61	

series of experiments made with varying amounts of fresh sewage sludge added to tap water flowing at three different ranges of velocity. The tap water had previously been deaerated by means of sodium sulfite and an excess of chlorine added to prevent biochemical oxidation. In this series, the observed reaeration rates for the sludge-tap water mixtures in the lowest velocity range, 4.2 to 5.0 ft. per min., averaged

only slightly less than for tap water alone at the same temperature and velocity of flow. In the two higher velocity ranges, 7.6 to 9.9 ft. per min., and 13.8 to 19.6 ft. per min., the sludge-tap water mixtures gave reaeration rates averaging 59 and 58 per cent, or little more than half the corresponding tap water rate. The marked reduction in these percentages, it will be noted, occurred as in Table II between the lowest and next lowest velocity ranges, corresponding roughly to the point of sharp upturn in the tap water rate curve shown in Fig. 3. This further indicates the tendency for the retarding effect of sewage on the reaeration rate to be manifest chiefly under turbulent conditions of flow.

Experiments with Various Separate Constituents of Sewage

In an effort to determine which of the major constituents of sewage might be responsible for lowering the rate of reaeration in mixtures with tap water under stream flow conditions, a series of individual experiments was made with a variety of substances, many of which are normally present in sewage. The results are given in Table IV.

Table IV.—*Results of Experiments with Various Substances Added to Tap Water, Flowing at Approximately the Same Temperatures and Velocities*

Substance Added	Concentration	Water Temp., °C.	Velocity of Flow, Ft./Min.	Reaeration Rate (r_0) at Obs'd Temp., Gms./Sq. Meter/Day		Per Cent of Tap Water Rate Observed
				Observed Rate	Tap Water Rate	
Diatomaceous earth:						
a. Heavy portion	——	21.5	22.2	23.6	25.6	92
b. Lighter portion	——	20.0	22.2	19.0	25.0	76
Urine	0.26% (vol.)	20.0	24.0	18.5	27.2	68
Activated sludge eff.	85% (vol.)	20.0	20.4	15.1	22.5	67
Feces suspension	132 p.p.m.	20.3	20.0	13.4	22.1	61
Dextrose-Na_2HPO_4-peptone	150 p.p.m.	19.4	21.9	11.8	24.4	48
Vegetable oil and gasoline	100 c.c./sq.m.	21.0	22.2	10.7	25.4	39
Mineral oil and gasoline	100 c.c./sq.m.	20.6	24.0	10.9	27.4	40
Soap	6 p.p.m.	20.0	21.2	12.6	23.7	49
Soap	30 p.p.m.	20.0	21.2	10.1	23.7	43
Soap	57 p.p.m.	20.8	24.0	10.5	27.5	38
Fatty acids (mixed)	10 c.c./sq.m.	19.8	22.2	9.9	25.0	40

Of the substances used which are normally present in sewage, each one had a measurable effect in lowering the reaeration rate, and the sum of the separate effects was greater than the total effect as indicated in the sewage itself. This is not unreasonable in view of the rapid decline in the reaeration rate in the presence of low percentages of sewage and the tendency for this effect to become stabilized in the higher ranges of concentration. Soap solution, recirculated at a velocity of 21.2 ft. per min., in a concentration estimated to be 25 per cent

(30 p.p.m.) of that in domestic sewage, gave a rate of reaeration equivalent to 43 per cent of the corresponding rate observed in tap water, whereas a soap concentration of 5 per cent of that in sewage gave a rate equivalent to 49 per cent of the tap water rate. These rates show for the one constituent, soap, a lowering of the reaeration rate approximately equal to that of sewage. In addition, urine in a concentration 85 per cent of that present in average domestic sewage, lowered the reaeration rate to 68 per cent of the tap water rate at a velocity of 24 ft. per minute. Feces, in a concentration half of that normally present in domestic sewage, lowered the reaeration rate to 61 per cent of the corresponding tap water rate under similar conditions. The figures for percentage concentration were based on average per capita soap consumption, and average per capita excrement figures in 100 gallons per capita daily flow of sewage.

None of the experiments in Table IV have been repeated to verify their accuracy and it is unwise, therefore, to draw definite conclusions from them. In general, however, they tend to confirm the effect noted in sewage-tap water mixtures and are included because they offer a clue as to the possible sources of this effect. The two experiments using diatomaceous earth were made with the settleable and the non-settleable fractions of 100 grams of diatomaceous earth repeatedly shaken in distilled water and allowed to stand overnight. They represent approximately the colloidal and heavier suspended fractions of diatomaceous earth. Another explanation which should be added regarding Table IV is in regard to the experiments made with oils to check the effect of oil films. The oils used were mixed with gasoline to give better spreading qualities but this did not insure a uniform film over the surface. There was a considerable accumulation of oil ahead of the paddles and at times the existence of even a monomolecular film over the paddles at points of greater agitation was doubtful.

Conclusions

The results of a series of reaeration measurements in a large recirculation channel described in the preceding paper of this series have indicated that the admixture of sewage or sewage sludge to tap water tends to retard the surface rate of atmospheric reaeration under stream flow conditions and especially at higher velocities, even when the percentage of sewage in the mixture is quite low, amounting to only a few per cent. This effect has been observed with quite a variety of other substances, some of which are normally present in sewage. Based on observations the sewage-tap water mixtures not exceeding 25 per cent of sewage, under conditions of agitation existing in the recirculation channel used but probably characteristic of this tank with regard to the magnitude of the velocity at which it occurs, the maximum effect, observed at velocities above 10 to 15 ft. per min., decreased rapidly below 10 ft. per minute. At velocities below 5 ft. per min., little significant difference was observed between the sewage and tap water reaeration rates, though a slight retardation was indicated.

Although no definite conclusions can be drawn from these experiments as to the basic cause, or causes, of the lowered rates of atmospheric reaeration observed in tap water when admixed with sewage or sewage sludge, the evidence at hand, as exemplified in Table IV, suggests very strongly that it may be associated with changes in surface tension of the water resulting from the presence of soaps, oils and other fatty derivatives in the sewage, and also possibly to the presence of organic colloids, which in sufficiently high concentrations might affect the rate of oxygen absorption. It has been noted by Langmuir [7] that the rate of diffusion of a soluble gas through the surface film of a solute liquid is influenced by the surface tension. In the case at hand, the disproportionately large reduction in the reaeration rate observed with relatively low concentrations of sewage and of substances like soap would tend to indicate that this retardation is mainly a surface phenomenon, virtually independent of the concentration of retarding substances beyond a certain optimum level, which appears to be reached in diluted sewage not far beyond the 25 per cent concentration point.

The fact that the retarding effect thus observed was at a minimum under conditions of quiescent flow and was increased very sharply with the transition to turbulent flow, is not inconsistent with this hypothesis. In a state of quiescence, the principal retarding influence in the absorption of atmospheric oxygen is the relatively slow replacement of oxygen-saturated water at the surface by undersaturated water from below, or as noted by Phelps,[8] the establishment of a diffusion gradient of rapidly diminishing oxygen concentration below the surface, with a very slow downward penetration of this gradient into the subsurface layers. Under these conditions, the net effect of any retardation in the surface rate of oxygen absorption on the speed of dispersion of the dissolved gas to the lower strata would be less proportionately than under a condition of turbulence, where the rate of surface film replacement is high and the absorption of atmospheric oxygen by the body of water as a whole is limited to a greater extent by the rate of passage of the gas through the surface film.

Whatever may be the more fundamental causes of the phenomenon observed, its practical significance in relation to stream pollution and to certain aspects of sewage treatment is fairly evident. In moderately and highly polluted streams, where concentrations of sewage, or of its equivalent in terms of industrial wastes, may range from 0.5 per cent to 10 per cent or more, an appreciable retardation in atmospheric reaeration means the imposition of a burden on the stream's recovery capacity quite distinct from and in addition to that which is represented by the oxygen demand of these wastes. In sewage treatment processes involving aeration, any similar braking action exerted on the rate of absorption of oxygen by the sewage likewise imposes a burden on the efficiency of such processes. Although the data obtained from these experiments have not shown definitely whether natural or artificial processes of purification may tend to modify the retarding effects

on reaeration observed, they have pointed toward the possibility that these effects may be considerably ameliorated by either one of these processes. If further studies should confirm this possibility, they would indicate a two-fold benefit to streams as resulting from extensive stream cleaning measures involving sewage and industrial wastes treatment; namely, a reduction in the B.O.D. load and an increase in the natural reaeration capacity of the streams. This question will need much further study, however, before it can be answered with any degree of certainty, both as regards the extent of such benefit to be expected and the relative adequacy of various methods of artificial treatment in removing those substances from sewage which bring about the retardation in oxygen recovery.

Acknowledgments

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THE SOLUBILITY OF ATMOSPHERIC OXYGEN IN SEWAGE

By W. Allan Moore

Junior Chemist, Stream Pollution Investigations, U. S. Public Health Service, Cincinnati, Ohio

In connection with studies of the rates of reaeration of polluted waters in progress at this station, there was some indication of a possible variation in the solubility of atmospheric oxygen in sewage as compared with that in clear water. It was decided, therefore, to make a direct study of the true oxygen solubility in sewage. The results of this investigation are given in the present paper.

Procedure

In order to have some basis for comparing the solubilities obtained, the solubility of oxygen in distilled water at various temperatures as determined by Fox [1] was accepted as a standard. These values are the basis for the calculations of Whipple and Whipple which appear in Standard Methods for the Examination of Water and Sewage.[2] However, since these latter values are given for temperature intervals of one degree only and it was necessary in our work to read the temperature of the liquids being used to one-tenth of a degree, the interpolated values as given by Streeter [3] were used.

Method of Attaining Saturation.—After much experimenting in order to find the best method of saturating the distilled water and sewage with atmospheric oxygen the diffused air method was selected. A fine spray of bubbles was obtained by forcing air through "Aloxite" aeration stones submerged in a column of liquid contained in a two liter graduated cylinder by means of an automobile fuel pump driven by a small motor. Although it was estimated that approximately 90 per cent saturation was attained within five minutes by this method of aeration, the current of air was allowed to pass through the liquid for thirty minutes to assure complete saturation. When saturation was reached, the cylinder was removed, stoppered, and inverted several times to remove any bubbles of air adhering to its sides. The temperature of the liquid was then taken. The liquid was allowed to stand for some time to assure the removal of all entrained air. It was then siphoned into the standard (250 ml. glass stoppered bottles) dissolved oxygen bottles and the analysis for the dissolved oxygen made.

In the aeration of sewage it was necessary to arrest biological action in order that saturation might be reached and maintained during the course of the analysis. In general two methods were found to be satisfactory for this purpose: (*a*) lowering of the pH to approximately 3.5 by means of sulfuric acid, or (*b*) by the addition of 3 cc. per liter of a mercuric chloride solution containing 2000 p.p.m. of $HgCl_2$. The sewage used in this study was of domestic origin, containing no trade wastes and having an average 5-day B.O.D. of approximately 350.

In Table I are given the values obtained for the solubility of atmospheric oxygen in distilled water using the aeration method above described. On comparing these values with the accepted values at the same temperature and pressure (all values are reported at 760 mm.) it is seen that the two sets of data agree very well.

The values obtained justify the use of this aeration method for determining the solubility of atmospheric oxygen in sewage. Though the rate of solution of atmospheric oxygen may not be as rapid in sewage as in distilled water, the thirty minute period of aeration was found to be sufficient to obtain complete saturation.

Analytical Methods Used.—In the determination of dissolved oxygen in sewage certain substances interfere with the Winkler procedure. It has been shown also that owing to the organic matter present, the Rideal-Stewart modification is not applicable to sewage. Theriault and McNamee [4] introduced a modification in the technique of the Wink-

TABLE I.—*Comparison of Solubility of Atmospheric Oxygen in Distilled Water with the Accepted Values as Determined by Fox*

Temperature °C.	Observed Solubility P.p.m.*	Accepted Value P.p.m.	Deviation
20.4	9.14	9.10	+0.04
21.1	9.00	8.98	+0.02
21.9	8.88	8.85	+0.03
22.9	8.73	8.69	+0.04
23.7	8.57	8.57	0.00
24.2	8.50	8.50	0.00
24.3	8.44	8.48	−0.04
24.6	8.44	8.44	0.00
24.6	8.44	8.44	0.00
24.6	8.43	8.44	−0.01
24.7	8.41	8.42	−0.01

* Winkler method used for determining dissolved oxygen.

ler method recommended for use in the presence of organic material. This method, hereafter referred to as the "short" method, consisted in shaking the alkalinized sample for 15 seconds, adding the sulfuric acid without allowing the precipitate to settle and titrating the liberated iodine immediately.

By the use of the "short" method, however, it was found that the determined solubility of oxygen in sewage was only about 84 per cent of its solubility in distilled water as is shown in Table II. The wide fluctuation in the results obtained by this method are probably due to the fluctuation in the amount and character of the constituents present in the sewage used.

Since the indicated solubility of atmospheric oxygen as determined by the "short" method appeared to be too low it was decided to try the effect of pre-iodinating the sewage before aeration. This procedure should not only eliminate the possibility of iodine being adsorbed in the

TABLE II

Experiment Number	Solubility of Oxygen in Sewage in Terms of Percentage of Distilled Water Solubility
1	77
2	86
3	87
4	84
5	90
6	84
7	85
8	84
9	81
10	88
11	80
Average	84

acidified sample but should also oxidize those substances present that interfere during the period of alkalinization. In this procedure the sample was acidified slightly with sulfuric acid and starch indicator solution added, followed by an excess of N/10 iodine solution. An excess of iodine was maintained for twenty minutes, when it was destroyed with N/10 sodium sulfite solution and the aeration carried out as usual, followed by the determination of the dissolved oxygen by the regular Winkler procedure.

The pre-iodination of the sewage before aeration gave an indicated solubility of approximately 88 per cent of that of distilled water as shown in Table III. This value, although slightly higher than that ob-

TABLE III

Experiment Number	Solubility of Oxygen in Sewage in Terms of Percentage of Distilled Water Solubility
1	79
2	94
3	95
4	83
5	91
6	94
7	87
8	92
9	82
10	91
11	85
Average	88

tained by the "short" method seemed to be too low and it was decided to try the vacuum method of Theriault and McNamee.[5]

Determination of Extraction Factor for Vacuum Method.—The vacuum method was selected as a reference method because it is free of many of the inherent errors of the volumetric procedures used in the determination of dissolved oxygen. Due to the fact that not all of the dissolved oxygen is extracted during the period the sample is under vacuum, it is necessary to determine the percentage of the oxygen that is extracted under a given set of conditions (same periods of agitation, same vacuum and temperature) and apply the correction factor thus obtained to all subsequent analyses. In order to obtain such a correction factor, distilled water was saturated with atmospheric oxygen and the dissolved oxygen then determined by the vacuum method. The actual dissolved oxygen present was determined by the straight Winkler procedure. The results obtained by this method using saturated distilled water are given in Table IV.

TABLE IV.—*Percentage of Recovery of Dissolved Oxygen by the Vacuum Method*

Experiment No.	Dissolved Oxygen Recovered P.p.m.	Dissolved Oxygen Present P.p.m.	Per Cent Recovery
1	7.48	8.76	85
2	7.69	8.85	87
3	7.35	8.52	86
4	7.60	8.52	89
5	7.33	8.52	86
6	7.58	8.14	92
7	7.74	8.53	91
8	7.68	8.48	91
9	7.60	8.28	90
10	7.15	7.94	90
11	7.62	7.94	96
12	7.78	8.15	95
13	7.60	8.15	93
14	7.45	8.53	87
15	7.60	8.15	93
		Average	90
		Standard Deviation	3

From the results given in the above table, the probable error of a single determination is calculated to be ± 2 per cent. Although this is a fairly large individual error, the method serves as a check on the volumetric procedures used in a series of experiments.

SOLUBILITY OF ATMOSPHERIC OXYGEN IN SEWAGE

In Table V are presented the results obtained for the solubility of atmospheric oxygen in raw sewage by the vacuum method, in terms of percentage of distilled water solubility.

The results obtained by the vacuum method indicate that the average solubility of oxygen in the sewage studied was 95 per cent of the distilled water solubility. While the percentage solubility values fluctuate considerably in the different experiments, it is believed that the average value is a better measure of the true solubility of oxygen in sewage than can be obtained by the use of the volumetric Winkler procedure. The fluctuations may be partly accounted for by the varying character of the sewage and by the necessity of applying a recovery factor in calculating the dissolved oxygen present.

TABLE V

Experiment Number	Solubility of Oxygen in Sewage in Terms of Percentage of Distilled Water Solubility
1	99
2	98
3	98
4	87
5	97
6	95
7	88
8	95
9	94
10	96
11	95
Average	95

SUMMARY

The use of the vacuum method indicates that the solubility of atmospheric oxygen in a domestic sewage tested was approximately 95 per cent of its solubility in distilled water.

The straight Winkler method is shown to give very accurate results in the determination of dissolved oxygen when no interfering organic material is present. The results obtained by this method check those obtained by the gasometric procedure within a few hundredths of one part per million. This confirms work done by previous investigators.

The "short" modification of Theriault and McNamee gave an indicated solubility of atmospheric oxygen in sewage approximately 11 per cent too low.

The oxidation of the sewage by means of iodine before aeration overcame to a certain extent the difficulty of determining the oxygen solubility by the Winkler method but the results obtained were still too low.

ACKNOWLEDGMENT

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DIGESTION EXPERIMENTS AT FLINT, MICHIGAN, ON SEWAGE SLUDGE, GARBAGE AND LIME SLUDGE MIXTURES

By Pierre R. Welch

Chief Chemist, Sewage Treatment Plant, Flint, Mich.

Experimental studies of the digestion of sewage sludge, garbage, and lime sludge were started at the Flint Sewage Treatment Plant (Figs. 1 and 2) in the fall of 1936. The experimental work was carried out throughout the winter of 1936 and 1937, and was completed July 25, 1937.

Fig. 1.—Flint sewage treatment plant. Imhoff tanks and drying beds.

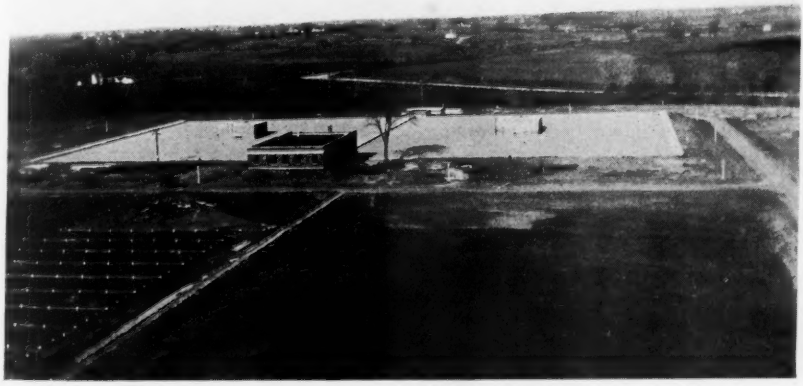

Fig. 2.—Flint sewage treatment plant. Dosing tanks, filters and aeration tank.

Purpose.—The main objectives of the experiments were as follows:

1. To determine how sewage sludge will digest under good control in heated digestion tanks.
2. To determine how a mixture of sewage sludge and garbage will digest under good control in heated digestion tanks.
3. To find out the effect of sludge from a water softening plant on the digestion rate of sewage sludge.
4. To find out the effect of sludge from a water softening plant on the digestion rate of a mixture of sewage sludge and garbage.

Description of the Experimental Separate Sludge Digestion Tanks and Equipment

Four steel tanks, each 5 ft. high by 4 ft. 5 in. in diameter and of 575 gal. capacity, were fitted out for digestion tanks (Fig. 3). A conical bottom 18 in. deep connected to a 1½ in. pipe served as a sludge draw-off. Sludge was drawn into tubs through a 1½ in. hose. A conical cover with 12 in. apron fitted loosely in the top, allowing it to float and relieve any undue pressure that might be caused by plugged gas lines or large additions of sludge. Sludge additions were provided for by a 3 in. tube extending through the cover and below the liquid level, and surmounted by a funnel. A stirring mechanism consisting of two 4 in. by 48 in. paddles mounted on a ¾ in. pipe was supported by a ½ in. pipe fastened across the tank. The stirring shaft extended through the center of the top to two arms and was sealed against gas leakage by another 3 in. tube extending below the liquid level. In the two tanks to which lime additions were made, six vertical boards were fastened to the lower paddle extending into the conical bottom. A single loop 1½ in. copper steam coil was suspended from the stirrer support just above the conical bottom and 3 in. from the wall. A 1½ in. sampling cock 6 in. above the conical bottom and a 1½ in. supernatant draw-off 45 in. from the tank bottom were installed. In addition, a 2 in. ell and riser pipe mounted 13 in. from the top was provided, for observation of the liquid level. Each tank was jacketed with 4 in. of sawdust held in place by burlap, lath and wire hoops, which greatly reduced the loss of heat.

Gas was drawn from the digester covers through ⅜ in. hose to individual gas holders (Fig. 4). The holders were 29 by 20 in. in diameter galvanized steel cylinders submerged in 55 gal. drums. A gas inlet riser pipe extended through the drum bottom to above the water level, and was fitted with valves for exhausting gas and draining entrapped moisture. Each holder was suspended on a counter-weighted cord and provided with a ¼ in. sampling petcock (Fig. 5).

The effective capacity of each digester was 410 gal. with the liquid level 5 in. below the top. The gas holder had a capacity of 5.4 cu. ft. and a calibrated rod was provided for measurements.

A Mitts and Merrill "Hog" type grinder was secured for grinding garbage. This grinder, directly connected to a 5 H.P. 1740 R.P.M. motor, had capacity exceeding our needs and worked very satisfactorily.

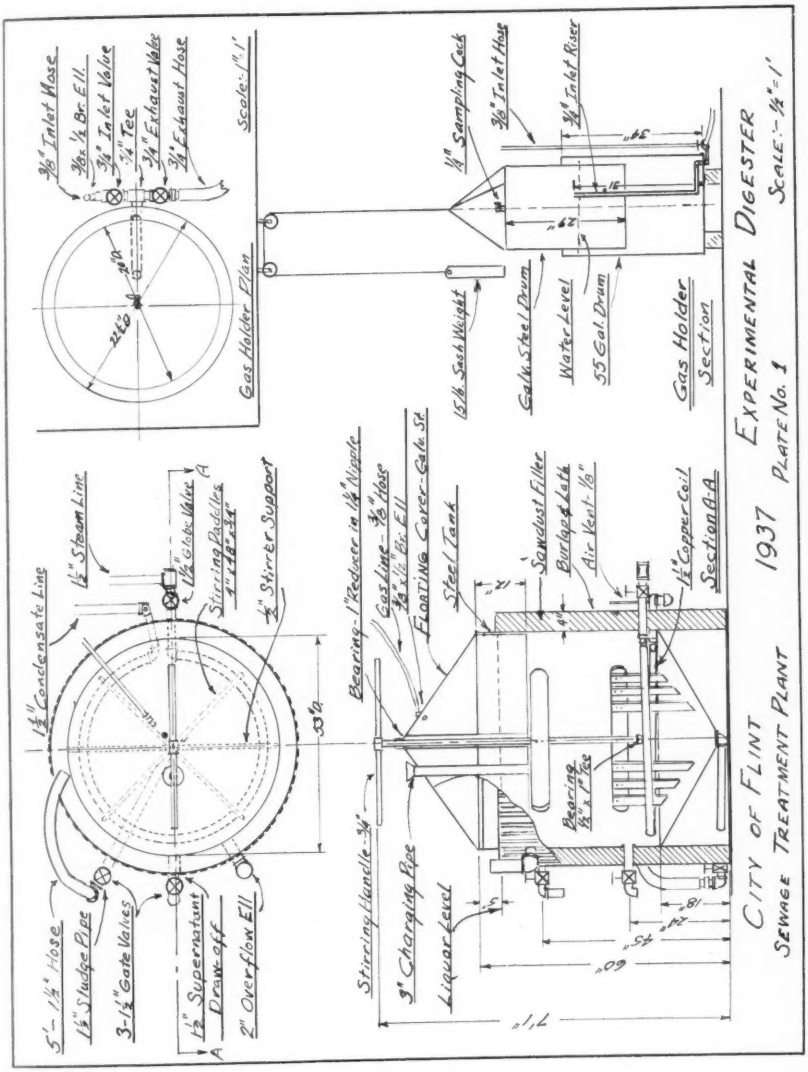
CITY OF FLINT
SEWAGE TREATMENT PLANT
1937
EXPERIMENTAL DIGESTER
PLATE No. 1
SCALE:- 1/4"=1'
Gas Holder Section
Gas Holder Plan
Scale:-1"=1'
Water Level
55 Gal. Drum
Galv. Steel Drum
Steel Tank
Floating Cover-Galv. St.
Liquor Level
Sawdust Filler
Burlap & Lath
Air Vent-3/8"
Section A-A
Bearing
Stirring Handle-36"
Stirring Paddles
Stirrer Support
Overflow Ell
Supernatant Draw-off
Sludge Pipe
Condensate Line
Steam Line
Inlet Hose
Inlet Valve
Tee
Exhaust Valve
Exhaust Hose
Sampling Cock
Inlet Riser
Globe Valve
Gate Valves
Hose
Charging Pipe
Copper Coil
Reducer
Gasket
Sash Weight

FIG. 3

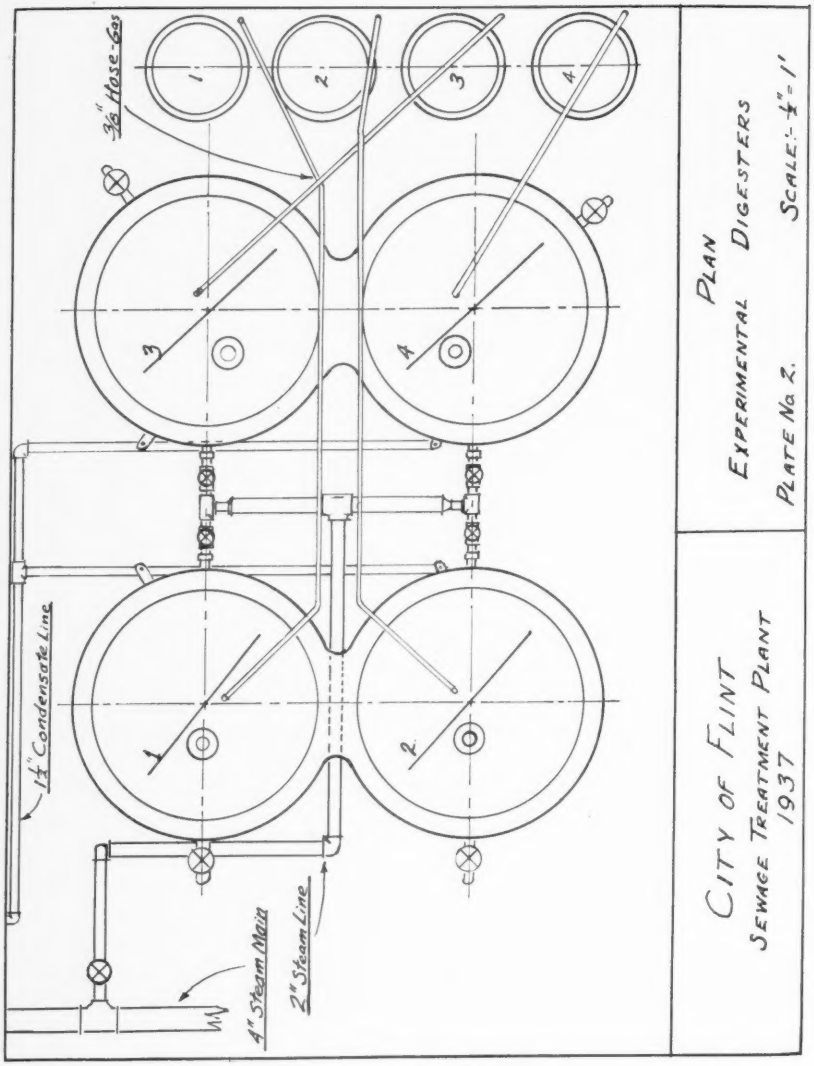
3/8" Hose-Gas
1
2
3
4
1½" Condensate Line
4" Steam Main
2" Steam Line
CITY OF FLINT
SEWAGE TREATMENT PLANT
1937
PLAN
EXPERIMENTAL DIGESTERS
PLATE No 2.
SCALE:- ½" = 1'

FIG. 4

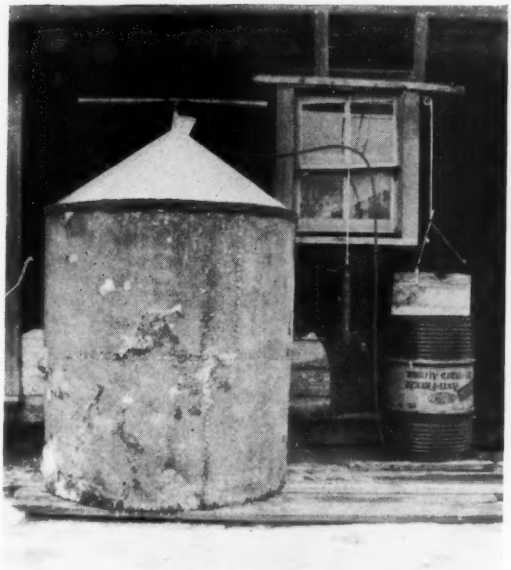

FIG. 5.—Experimental digester and gasometer.

PREPARATION OF CHARGES

Raw Sewage Sludge.—Raw sludge was obtained by suspending 15 gal. tubs in the sedimentation compartment of one of the Imhoff tanks.

Garbage.—Whenever garbage was needed, we would notify the garbage department and they would collect about 5 bushels of garbage by taking a small portion from each truckload during a day's run. In this way, a representative sample would be obtained for that particular day. The next sample would be on a different day of the week. The garbage was not hand-picked but was taken as it came off the trucks. Paper, bottles, tin cans and other similar materials were removed before grinding the garbage. After the garbage was ground, water was added and a slurry was made up containing a solid content between 10 and 15 per cent.

Lime Sludge.—Lime sludge was obtained from one of the local factories' water softening plants. The lime sludge was washed about ten times by decantation so as to remove excess alkalinity. Lime from small softening plants was found to contain either excess caustic alkalinity or if non-carbonates were removed, excess Na_2CO_3 occluded in the sludge. This carbonate alkalinity was most difficult to remove.

ESTIMATED RATIOS OF SEWAGE SLUDGE, GARBAGE AND LIME SLUDGE

Plant records show that about 19,400 lb. of solids per day on a dry basis are deposited in the Imhoff tanks. Assuming a population of 156,000, this would be equivalent to 0.124 lb. per capita per day.

Garbage studies in 1934 indicated an average of 0.176 lb. per cap. per day on a dry basis or 27,400 lb. based on a population of 156,000.

Computation indicated that with an average water consumption of 15 m.g.d., the sludge produced from a softening plant would be about 54,000 lb. per day on a dry basis. This is equivalent to 0.346 lb. per cap. per day, based on a population of 156,000.

Ratios of the various mixtures:

Sewage sludge to garbage—1 : 1.42
Sewage sludge and garbage to lime sludge—1 : 1.15
Sewage sludge to lime sludge—1 : 2.79

Seeding and Starting Digestion Tanks

About 110 gal. of actively digesting sludge was added to each digester on December 22, 1936. The analysis of this sludge was 93.7 per cent moisture and 52.8 per cent volatile and a pH of 6.3. Imhoff tank effluent was added to bring the water level up to within 5 in. of the top. The covers were placed in position and the gas lines were connected to the gasometers. The tanks were then slowly heated to 90° F. and stirred thoroughly. Gas production was measured daily, starting December 22 and no sludge was added until January 6, 1937.

A daily charge of 1 lb. of total solids on a dry basis to each tank was started on January 7, 1937. A great deal of trouble was experienced with leaks at the beginning. Due to these leaks and many other difficulties, it took until Feb. 10 before the daily charge was increased to 2 lb. per day. A 2 lb. charge was added daily from Feb. 10 to Feb. 15. A 4 lb. charge was added from Feb. 15 to March 2. From March 2 to the end of the experimental studies, a 6 lb. charge of total solids was added daily to each tank.

Addition of lime sludge was started on March 8.

Daily Charges to Each Digestion Tank

The daily charges of 6 lb. to each tank of total solids after March 8, 1937, were divided as follows:

Digester 1—2.5 lb. of sewage sludge plus 3.5 lb. of garbage.
Digester 2—6.0 lb. of sewage sludge plus various ratios of lime sludge.
Digester 3—6.0 lb. of sewage sludge alone.
Digester 4—2.5 lb. of sewage sludge plus 3.5 lb. of garbage plus various ratios of lime sludge.

The only difference in loading between Digester 1 and 4 was in the lime sludge added to Digester 4—otherwise they both received the same organic load. The same held true for Digesters 2 and 3. Thus the effect that the lime sludge had on sewage sludge alone, and on a mixture of sewage sludge and garbage was indicated.

Method Used in Adding Daily Charges and the Operation of the Tanks

Everything added or withdrawn from the tanks was weighed. The 6 lb. charge was divided into two portions of 3 lb. each and one 3 lb. charge was added between 9 and 10 A.M. and the other charge was added between 9 and 10 P.M. An equivalent volume of either supernatant liquor or digested sludge was withdrawn from a digester before the charge was added. Each tank was heated after the morning addition and the temperature was brought up to 94° F. By the following morning, the temperature would drop between 88° and 90° F. Gas readings were taken every two hours and gas was exhausted when about 4.5 cu. ft. of gas had been collected. Digesters 1 and 3 were stirred thoroughly after the charges were added and during heating. Digesters 2 and 4, which received lime sludge in addition to the organic charge, were stirred thoroughly after the charges were added and then once every hour for seven hours.

The tanks were located in a heated building and were well insulated, and therefore no difficulty was experienced in maintaining an average temperature between 90° and 92° F.

Discussion of the Data

The tabulation of the experimental data was made difficult by the fact that it was necessary for us to try various combinations of the different materials. This variable loading resulted in data which are difficult to present. No attempt will be made to give detailed tabulations of the daily data that were recorded. The results will be divided into several periods in accordance with the variable loadings.

As mentioned previously, the digesters will be designated as follows:

Digester 1—Sewage sludge plus garbage.
Digester 2—Sewage sludge plus lime sludge.
Digester 3—Sewage sludge alone.
Digester 4—Sewage sludge plus garbage plus lime sludge.
Digesters 1 and 4 received the same organic load.
Digesters 2 and 3 received the same organic load.

Ether-Soluble Fats.—Several analyses were made on the raw sewage sludge, digested sludge and garbage to determine the fat and grease contents.

	Ether Soluble, Dry Basis Per cent
Raw sewage sludge	34.0
Garbage	17.1
Digested sludge	
Digester 1	2.2
Digester 2	4.9
Digester 3	6.0
Digester 4	0.3

TABLE I.—*Period from Dec. 23, 1936 to Mar. 8, 1937. Digesters 1, 2, 3 and 4*

This table gives a summary of the organic seeding period during which the pounds of organic solids added daily, on a dry basis, were increased from 1 lb. to 6 lb. for each digester. Several leaks were repaired on Digester 2.

Dec. 25, 1936 to Mar. 8, 1937

Digester	1	2	3	4
Total gas prod., cu. ft.	1,274.0	875	1,018	1,187
Total lb. solids added (dry basis)	161	198	160	197
Total lb. vol. sol. added	127	118	117	127
Total lb. line added		36.4		36.4
Cu. ft. gas per lb. vol.	10.0	7.4	8.7	9.3

TABLE II.—*Period from Mar. 29 to May 16, 1937*

The summary in this table is for Digesters 1 and 4. Lime sludge added to Digester 4 was 5.8 lb. per day from Mar. 29 to April 14 and 7.0 lb. per day from April 14 to May 4. No lime sludge was added from May 4 to May 16.

The reason that this period was tabulated separately was because considerable trouble was being experienced with Digester 2.

Digesters 1 and 4		Mar. 29 to May 16
Digester	1	4
Gas production, cu. ft.	2,504	1,820
Corrected for CO_2 loss		1,945
Avg. % CO_2	36.5	32.3
Lb. solids added	288	519
Lb. volatile solids added	235	235
Lb. line solids added		205
Cu. ft. of gas per lb. vol.	10.6	7.7
Corrected for CO_2 loss		8.3
Lb. digested sludge drawn	23	309
Avg. % volatile	56.2	49.4

TABLE III.—*Period from Mar. 29 to July 7, 1937*

This table gives a summary of the more important data for Digesters 2 and 3 for the period after the lime additions to 2, which is given in Table IV. Digester 2 became unbalanced biologically because it was overloaded. We were unable to restore normal conditions of digestion and finally had to discontinue operation of this tank. No lime sludge was added to Digester 2 during this period.

Digesters 2 and 3		Mar. 29 to July 7
Digester	2	3
Cu. ft. of gas produced	4,039	4,859
Lb. solids added	869	624
Lb. volatile solids added	526	440
Lb. of lime added	105	—
Cu. ft. gas per lb. vol. sol.	7.7	11.1
Lb. digested sludge drawn (dry basis)	543	136
Avg. % volatile	47.5	49.1

Note: Tables I, II and III cover the periods during which some trouble was being experienced, whereas Tables IV, V and VI cover the periods of very successful operation, during which satisfactory results were obtained.

TABLE IV.—*March 8 to 29, 1937*

This table gives a summary of the results that were obtained for Digesters 2 and 3 with an increasing lime sludge ratio. The lime ratio on Digester 2 was increased from 0.94 to 2.33 parts of lime sludge to 1 part of sewage sludge during the 3-week period.

The digestion rate of Digester 2 was very good during this period, although the lime sludge added daily was 14.0 lb. to 6.0 lb. of sewage sludge. A total of 215.6 lb. of lime sludge was added to Digester 2 in addition to 126 lb. of sewage sludge. No digested sludge had been drawn from any of the four digesters until April. Consequently Digester 2 became greatly overloaded, which was the main reason why this tank became unbalanced. The sludge level was ⅔ in Digester 2 compared to about ⅓ full in Digester 3. Sludge drawing was started in April but we were not able to get Digester 2 working properly and finally had to discard it.

As the lime ratio increased, the CO_2 content of the gas from Digester 2 decreased. This loss in CO_2 is brought about by a recarbonation and absorption of the CO_2 by the lime sludge. A correction is made for this loss of CO_2 as indicated in the table.

It is of interest to note that the gas production was greater in Digester 2, which received the lime sludge, as compared to 3.

When the lime ratio was increased to 2.33: 1 of sewage sludge, the per cent of CO_2 in Digester 2 dropped as low as 16 per cent compared to 31 per cent in Digester 3.

Summary, Digesters 2 and 3, March 8 to 29, 1937

	Digester	March 8–15	March 15–22	March 22–29	Total or Avg.
Lb. lime added daily	2	5.6	11.2	14.0	
Lime ratio to sewage solids	2	0.94	1.87	2.33	
Gas prod., cu. ft	2	296	324	321	941
Corrected for CO_2 loss	2	321	351	350	1,022
Gas prod	3	280	292	339	911
Avg. % CO_2	2	28.4	27.2	26.1	
	3	31.9	32.6	31.8	
% CO_2 absorbed	2	15.3	23.2	23.8	
Cu. ft. gas/lb. vol. charged	2	9.5	10.0	10.2	
Corrected for CO_2 loss	2	10.3	10.8	11.2	
	3	9.0	9.0	10.7	
Wet sludge added, lb	2	839	1,123	1,160	3,122
	3	631	724	676	2,031
Supernatant draw off, lb	2	839	1,123	1,160	3,122
	3	631	724	676	2,031
Dry solids added, lb	2	81	120	140	341
	3	42	42	42	126
Lime solids added, lb	2	39	78	98	215
Vol. solids added, lb	2 and 3	31	32	32	95
Avg. % solids, sludge added	2	9.67	10.70	12.00	
	3	6.60	5.80	6.21	
Avg. % volatile, sludge added	2	38.7	27.2	22.60	
	3	74.9	77.6	75.3	
Wt. of gas produced, lb	2	15.8	17.0	16.5	49.3
Corrected	2	18.1	19.9	19.9	57.9
	3	15.8	16.6	19.1	51.5
Days for total displacement	2	30.5	23	22	
	3	41	35	38	

No sludge drawn during above periods.

TABLE V.—*March 8 to 29, 1937*

This table gives a summary of the results that were obtained for Digesters 1 and 4. The lime ratios were lower in Digester 4 than in Digester 2. No difficulty was experienced with this digester. The Co_2 loss was not very much in 4 compared to 2 and no correction was made for it. The gas production was greater in 4 than in 1.

Summary, Digesters 1 and 4, March 8 to 29, 1937

	Digester	March 8–15	March 15–22	March 22–29	Total or Avg.
Lb. lime added daily	4	2.31	4.62	5.8	
Lime ratio to other solids	4	0.39	0.77	0.97	
Gas production, cu. ft.	1	398	392	446	1,236
	4	402	405	454	1,261
Avg. % CO_2	1	38.4	37.6	37.2	
	4	38.4	36.0	36.0	
Cu. ft. of gas per lb. vol. charged	1	11.0	10.6	12.4	
	4	11.1	11.0	12.6	
Wet sludge added, lb.	1	480	509	492	1,481
	4	568	673	694	1,935
Supernatant draw off, lb.	1	480	509	492	1,481
	4	568	673	694	1,935
Dry solids added, lb.	1	42	42	42	126
	4	58	74	82	214
Lime solids added, lb.	4	16	32	40	88
Vol. solids added, lb.	1	36	37	36	109
	4	36	37	36	109
Avg. % solids, wet sludge	1	8.74	8.27	8.54	
Charged	4	10.23	11.05	11.90	
Avg. % volatile, sludge added	1	86.6	87.7	85.7	
	4	62.4	49.6	43.6	
Wt. of gas produced, lb.	1	24.5	23.9	37.4	75.8
	4	24.7	24.2	26.0	74.9
Days for total displacement	1	53	50	52	
	4	45	38	37	

No sludge drawn during above periods.

TABLE VI.—*May 16 to July 24, 1937*

This table gives a summary of results for Digesters 1 and 4 for four periods during which the lime sludge ratio was increased to 2.0 parts of lime to 1 part of sewage sludge. The results in this series were very good and clearly indicate that a larger amount of lime sludge could be handled.

As the lime sludge is increased, a drop in the CO_2 content occurred.

The total gas production in Digester 1 was 3,901 cu. ft. The total gas production in 4 was 3,461 cu. ft. The total gas production in 4 corrected for CO_2 loss was 3,725 cu. ft. Using the corrected figure the gas produced by Digester 4 was 176 cu. ft. less than the gas produced by Digester 1. This difference is negligible when we consider that the CO_2 analysis was made once in 24 hours.

When the lime ratio was increased 2 to 1, from July 15 to July 24, an average of 33.6 per cent of the CO_2 was absorbed from the gas produced by Digester 4.

TABLE VI

Summary, Digesters 1 and 4, May 16 to July 24, 1937

	Digester	May 16–June 8	June 9–29	June 30–July 14	July 15–24	Total or Avg.
Lime added, lb.	4	7.0	9.0	10.5	12.0	
Lime ratio to other solids		1.17	1.50	1.75	2.0	
Gas production, cu. ft.	1	1,353	1,209	822	516	3,900
Gas production, cu. ft.	4	1,281	1,082	666	431	3,460
Gas production, corrected	4	1,339	1,169	735	482	3,725
Avg. % CO_2	1	34.2	34.6	34.4	34.9	
Avg. % CO_2	4	31.5	29.5	27.7	27.4	
Avg. % CO_2 absorbed	4	11.7	22.5	29.7	33.6	
Cu. ft. gas/lb. vol. charged	1	11.7	11.8	11.2	11.7	11.6
	4	11.1	10.6	9.1	9.8	10.3
Corrected	4	11.6	11.4	10.1	10.9	11.1
Wet sludge added, lb.	1	1,612	1,357	1,005	599	4,573
	4	2,340	2,043	1,599	994	6,976
Wet sludge removed, lb.	1	550	1,100	700	400	2,750
	4	1,700	1,838	1,224	890	5,652
Supernatant draw-off, lb. (approx.)	1	900	120	120	100	1,240
	4	425	100	150	75	750
Dry solids added, lb.	1	144	126	90	57	417
	4	312	315	247	171	1,045
Lime solids added, lb.	4	168	189	137	114	628
Vol. solids added, lb.	1 and 4	115	102	73	44	335
Dry solids removed, lb.	1	22	48	29	18	117
	4	164	256	188	151	759
Vol. solids removed, lb.	1	12	26	16	10	64
	4	81	125	93	73	373
Avg. % solids, wet sludge added	1	8.91	9.28	8.95	9.52	9.12
	4	13.33	15.40	15.45	17.20	15.00
Wet sludge removed	1	3.96	4.33	4.22	4.62	4.27
	4	9.64	13.92	15.40	17.04	13.42
Avg. % vol. sludge added	1	80.2	81.3	81.0	77.5	80.3
	4	37.0	32.6	29.5	25.8	32.0
Avg. % vol. sludge removed	1	55.3	54.3	55.6	54.8	55.0
	4	49.16	49.2	49.6	48.7	49.3
% Red. vol. matter	1	69.4	72.7	70.6	64.7	70.0
Wt. of gas produced, lb.	1	78.7	70.5	47.8	30.3	227.3
	4	71.6	58.7	35.1	22.6	188.0
Corrected	4	77.7	68.2	42.7	29.2	217.8
Days for total displacement	1	54	54	55	61	
	4	37	37	34	37	

TABLE VII

This table gives a summary of the total gas production, total pounds of dry solids, volatile solids and lime solids added to each digester.

Totals for Entire Series—Dec. 23, 1936, to July 24, 1937

	1	2	3	4	Grand Total
Total gas prod., cu. ft.	8,917	5,857	6,790	7,730	29,294
Total solids added, lb. (dry basis)	993	1,410	911	1,978	5,292
Total vol. solids added, lb. (dry basis)	807	740	653	807	3,007
Total lime solids added, lb. (dry basis)		357		959	1,316

TABLE VIII

This table gives a summary of the supernatant liquor data for all periods, pH, 5-day B.O.D., volatile acids (Buswell's method) and ammonia determinations.

Supernatant Liquor Data
Averages For All Periods

	1	2	3	4
Per cent total solids	0.47	0.23	0.22	0.66
Per cent settleable solids (Buswell's method)	0.08	0.05	0.03	0.14
pH	7.7	7.1	7.0	7.9
B.O.D. in p.p.m. 5-day	1,850	500	550	1,500
Vol. acids (Buswell's method), p.p.m.	55	72	36	60
NH_4, p.p.m.	425	200	200	400

GENERAL DISCUSSION

Addition of lime sludge to digesting sewage sludge increased the gas production during the initial stage for a period of about three weeks. But as the concentration of the lime sludge in the digester increased, the gas production was slightly lower than that produced in a digester to which no lime was added. This increase in gas production was noted in Digesters 2 and 4 from March 8 to March 29.

The volume of lime sludge that a digester could handle was dependent to a large degree on the rate of digestion. If the sludge was digesting actively, there was a definite stratification of organic sludge and lime sludge. In order to aid in bringing about this stratification, it was necessary to add vertical extensions to the lower stirring paddle and stir the sludge in the digesters which received lime about once every hour, as previously mentioned. In this way, gas bubbles would form on the organic particles and bring them up to the scum layer, whereas the inert lime sludge particles would settle to the bottom with the digester sludge. For example, the daily volume of digested sludge drawn from Digester 4 was about 10 gallons. The nominal detention period of the lime sludge in the digesters was approximately 12 days because the mixture of lime sludge and digested organic sludge was maintained at a volume of about 120 gallons.

In the period from July 20 to July 24, an analysis of the digested sludge from Digester 4 gave the following results:

69.4% $CaCO_3$, 47.9% tot. solids, 56.5% volatile.

This was a reduction of 86 per cent of volatile matter in the organic sludge added, when corrected for the loss of CO_2 from $CaCO_3$, upon ignition.

It is evident that within an actively digesting tank, the lime sludge that is added will separate from the organic sludge and settle to the bottom where it can be drawn out daily.

Conclusions

The following conclusions are drawn from these experimental studies:

1. Flint sewage sludge and garbage, in proportions actually produced, digest readily, producing 11.5 cu. ft. of gas per pound of volatile matter. Garbage averaged 91 per cent volatile matter and the mixture averaged 83 per cent. The estimated gas production, based on the results obtained from the experimental work, would be approximately 445,000 cu. ft. per day for the entire city.

2. Flint sewage sludge digests readily, producing 10 cu. ft. of gas per pound of volatile matter. Raw sewage sludge averaged 75 per cent volatile. The estimated gas production, based on the experimental work, would be approximately 155,000 cu. ft. per day for the entire city, including 10,000 cu. ft. per day from the secondary tank sludge.

3. A mixture of sewage sludge, garbage and lime sludge, in proportions estimated to be produced, *i.e.* one part sewage plus garbage solids to 1.16 parts lime sludge, digests readily without any appreciable decrease in gas production because of the addition of the lime sludge.

4. A mixture of sewage sludge and lime sludge, in proportions of 1 part sewage sludge to 2 parts lime sludge, digests readily, producing slightly smaller amount of gas than sewage sludge alone, but a gas with lower CO_2 content. The studies indicated that a higher ratio of lime could be handled.

5. Proportions as high as 2 parts of lime sludge to 1 part of a mixture of sewage sludge and garbage digest readily but produce a slightly lower amount of gas than sewage sludge and garbage alone but a gas with a lower CO_2 content.

6. With the addition of separate sludge digestion tanks to the present sewage treatment plant, all of the garbage from the City of Flint could be digested, producing a valuable by-product in the gas that can be collected.

These studies were made possible with the help and cooperation of the following individuals:

Mr. Walter R. Drury of the consulting engineering firm of Shoecraft, Drury and McNamee of Ann Arbor, Mich., for his many sugges-

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Prof. H. E. Babbitt, Professor of Sanitary Engineering, University of Illinois, for his comments and suggestions in a private communication.

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Mr. John Norgaard, chemist at the Sewage Treatment Plant, who carried out most of the experimental work and control of the experiments.

Mr. Ira Dowd, senior plant operator, for the construction and erection of the digestion tanks and other appurtenances.

A MODIFIED EIJKMAN MEDIUM FOR THE ISOLATION OF ESCHERICHIA COLI FROM SEWAGE

By A. A. Hajna and C. A. Perry

Bureau of Bacteriology, Maryland State Department of Health, Baltimore, Maryland

In a previous study,[1] a modified Eijkman test was found to be an efficient means to determine quantitatively *Escherichia coli* in sewage. The carbohydrate used in the modified medium was dextrose. However, results obtained from a more recent study [2] on the ability of *Escherichia* organisms to decompose various carbohydrates and alcohols with production of gas at 46° C., indicated that lactose could also be utilized by *Escherichia coli* in the modified Eijkman medium of the authors as readily as dextrose.

The purpose of the investigation was to determine which of the two carbohydrates (dextrose and lactose) yielded the most positive confirmations for *Escherichia coli* in sewage as evidenced by the production of gas at 46° C.; and whether sodium formate could accelerate the production of gas from the two sugars. The procedure, as carried out in the previous study,[1] was used.

Media Used in the Comparison

Lactose broth was prepared according to *Standard Methods of Water Analysis* (1936, 8th edition). The basic formula for the modified Eijkman medium was that described in a previous report.[1] Lactose (0.3 per cent) was substituted for dextrose, and sodium formate (0.1 per cent) added as indicated in Table I. A tube temperature of 46° C. $\pm$ .5° C. (U. S. Bureau of Standards certified thermometer) was obtained in a water-jacketed Castle incubator.

Results

Results obtained from the examination of twenty-five samples of raw sewage for *Escherichia coli* and the colon group are given in Table I. Five hundred and eighty-five tubes of each medium were similarly inoculated. The substitution of lactose for dextrose in the modified Eijkman medium resulted in the recovery of more *Escherichia coli* from sewage at 46° C. than when dextrose, dextrose plus sodium formate or lactose plus sodium formate were used at this temperature. Not only was more *Escherichia coli* obtained with the lactose medium but a greater percentage of gas tubes were confirmed for this organism. The addition of 0.1 per cent of sodium formate to the lactose medium resulted in a decrease of the number of *Escherichia coli* isolated.

Fewer tubes of the modified Eijkman medium containing dextrose were positive for *Escherichia coli* than those containing lactose, dextrose plus formate, or lactose plus formate. The respective numbers being 184 against 230, 200 and 213. Lactose broth at 37° C., however,

TABLE I.—*Isolation of* Escherichia coli *at 46° C. From Tubes of Dextrose and Lactose Media Similarly Inoculated with 25 Samples of Sewage*

	Media				
	S.L.	D46	L46	DF46	LF46
Total tubes inoculated*	585	585	585	585	585
Tubes having gas at 48 hours	330	231	265	269	259
(*a*) Tubes having gas at 24 hours	321	222	255	256	251
(*b*) Tubes having gas only at 48 hours	9	9	10	13	8
Total confirmations, coli-aerogenes group	306	210	245	243	231
(*a*) 24 hours gas tubes confirmed	302	205	240	239	227
(*b*) 48 hours gas tubes confirmed	4	5	5	4	4
Total confirmations, *Escherichia coli*	178	184	230	200	213
(*a*) 24 hours gas tubes confirmed	176	180	225	196	211
(*b*) 48 hours gas tubes confirmed	2	4	5	4	2
Per cent of gas tubes confirmed for coli-aerogenes group	92.8	90.9	92.5	90.4	89.2
Per cent of gas tubes confirmed for *Escherichia coli*	54.0	79.7	86.7	74.4	82.2

S.L. Standard lactose broth, 8th Ed. *Standard Methods of Water Analysis*, A. P. H. A.
D46. Basic medium[1] plus dextrose at 46° C.
L46. Basic medium[1] plus lactose at 46° C.
DF46. Same as D46 with addition of 0.1 per cent of sodium formate.
LF46. Same as L46 with addition of 0.1 per cent of sodium formate.
* Each dilution inoculated in triplicate up to 10^{-10}.

had only 178 tubes from which *Escherichia coli* could be isolated. While a greater number of positives resulted from the addition of sodium formate to the dextrose medium at 46° C.,* the reverse was true when lactose was used.

COMMENTS AND SUMMARY

There is a growing need for an efficient method for the isolation of *Escherichia coli* from sewage, water, oysters, and possibly other materials.

Modified Eijkman media containing dextrose and lactose, with and without sodium formate have again been found superior to standard lactose broth both in the number of isolations of *Escherichia coli* made from sewage and in the *Escherichia coli*. The substitution of lactose for dextrose in a modified Eijkman medium has resulted in a greater number of positive isolations of *Escherichia coli*.

Of 585 lactose broth tubes inoculated with sewage, only 54.0 per cent of those giving gas confirmed for *Escherichia coli* against 86.7 per cent of a corresponding series using Eijkman lactose broth. Thus standard lactose broth at 37° C. has been found only slightly more than

* A study of lower temperatures is being made at present.

half (62.5 per cent) as efficient as Eijkman lactose broth at 46° C. for the isolation of *Escherichia coli* from sewage. The substitution of lactose for dextrose in the authors' Eijkman medium resulted in the recovery of more *Escherichia coli* from sewage, while the addition of 0.1 per cent of sodium formate decreased the efficiency of the lactose medium.

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THE BIOCHEMICAL OXYGEN DEMAND TEST AND OXIDATION IN SEWAGE TREATMENT *

By C. C. Ruchhoft

Principal Chemist, U. S. Public Health Service, Stream Pollution Investigations, Cincinnati, Ohio

The natural biological purification processes in sewage treatment are oxidation reactions in which the unstable organic compounds of sewage are oxidized aerobically by the bacteria and plankton or anaerobic decompositions carried on by the flora and fauna in the absence of dissolved oxygen. A discussion of the first of these processes in sewage treatment and the use of this principle in measuring the purification accomplished will be considered in this paper.

The Course of Oxidation of Organic Matter

In natural purification, with an excess of oxygen always maintained, the unstable organic compounds in all states of dispersion are oxidized by the bacteria to simple inoffensive end products. This oxidation reaction takes place in two stages. During the first stage nitrogenous and carbonaceous materials are attacked and broken down. The carbonaceous materials are oxidized to carbon dioxide and water together with small amounts of humus. The nitrogen is left in the form of ammonia at the end of this stage. A large variety of bacteria play a part in this carbonaceous oxidation.

The second stage or nitrogenous oxidation is carried out by two genera of bacteria. One genus, the *Nitrosomonas,* is responsible for the oxidation of the ammonia to nitrite. Another genus, the *Nitrobacter,* then oxidizes the nitrite to nitrate. The oxidation of ammonia does not take place in polluted waters until the 12th to 14th day or thereabout after more than 90 per cent of the carbonaceous oxidation has been completed. Consequently polluted waters or sewage effluents that have been oxidized to the nitrification stage never become anaerobic or septic, unless fresh pollutional material is added.

These oxidation reactions are motivated by bacteria and plankton and are, therefore, biochemical. The reactions take place only while the bacteria are active, *i.e.,* during their multiplication. When toxic substances are not present to interfere, the multiplication of the bacteria proceeds rapidly to a maximum level depending upon the concentration of the food (organic waste). During this stage of bacterial multiplication oxygen is rapidly consumed. The bacteria-eating plankton serve to reduce the number of bacteria thus providing conditions for their continuous growth. In this manner bacterial multiplication is stimulated and the oxidation of organic matter proceeds to completion. Careful studies have indicated that one of the functions of the

* Presented at the Michigan Sewage Works Operators Conference, March 31 to April 2, 1937.

animal plankton in this oxidation reaction is thus to stimulate the production of bacterial cells which are required for the complete oxidation of the organic matter.

The Biochemical Oxygen Demand Test

The biochemical oxygen demand, or B.O.D., test is a direct application of the biochemical oxidation taking place in streams and polluted waters. In this test conditions are maintained artificially so that the reaction can proceed undisturbed during the time interval chosen for observation; and the organic matter present in a sample is determined in terms of the oxygen required to oxidize it. This test is easily carried out by determining the dissolved oxygen content before and after the desired period of incubation on suitably prepared portions of the sample.

The development of the oxidation theory, the application of this concept to the measurement of organic matter and the improvement of the oxygen demand test have been reviewed by Theriault.[1]

The detailed procedure for the biochemical oxygen demand test is described by Theriault[2] and by the Joint B.O.D. Committee of the Great Lakes and Ohio River Boards.[3] The procedure is also given in the Standard Methods of Water Analysis[4] of the American Public Health Association.

Briefly the test consists of a determination of the dissolved oxygen in each of two duplicate portions of sample, one at the start and the other after incubation in a tightly stoppered filled bottle. The test is usually made at a standard temperature of 20° C. and for an incubation period of 5 days. The difference in the oxygen content of these two portions expressed in (milligrams per liter) p.p.m. is the biochemical oxygen demand of the sample for the incubation period and at the temperature used. If the sample has been diluted to make the test the loss of oxygen in the diluted portion in milligrams per liter must be multiplied by the dilution factor to obtain the oxygen demand of the original sample.

For purposes of comparison there is an advantage in making occasional tests at various incubation periods such as 2, 5, 7, 10, 12, 15, 20 and 25 days. By this means the course of the deoxygenation curve may be followed and comparisons may be made with the assurance that results from comparable sections of the deoxygenation curve are being used.

Certain other precautions must be taken to insure comparable results. Important among these are: clean glassware, accurately controlled incubator temperature, tightly stoppered and properly sealed bottles, careful neutralization of toxic materials, if present, proper seeding of samples where this is necessary, the use of satisfactory dilution water where dilution is required, the careful adjustment of dilutions to obtain adequate oxygen depletions, and the inclusion of blank controls on the dilution water and the seed where these are used.

Advantages and Limitations of the Oxygen Demand Test

This test has advantages over strictly chemical tests such as the permanganate oxygen consumed test or the organic carbon determination in that it simulates very closely the reaction taking place under natural conditions and includes oxygen used in both carbonaceous and nitrogenous oxidation.

The limitations of the test include: the rather long incubation periods, the inhibition by toxic substances of normal biological growth with consequent reduction of biochemical oxidation and the interference of various chemical constituents with the Winkler reagents used in the determination of the dissolved oxygen thereby producing erroneous dissolved oxygen results. Satisfactory modifications of the Winkler procedure are given by Theriault [2, 5] and by Theriault and McNamee [6] to prevent interference due to iron salts, nitrites, organic matter, hypochlorites and sulfite wastes. Another limitation is caused by the relatively low solubility of oxygen in water (9.17 p.p.m. at 20° C. and 760 mm.). Consequently samples containing organic matter requiring oxygen in excess of this supply for their oxidation must be diluted with an oxygen containing water of suitable characteristics. Distilled water, stored at 20° C. until saturated with oxygen and to which 0.3 gram of sodium bicarbonate is then added, is recommended by the Joint B.O.D. Committee Report.[3] A phosphate buffered water is advocated by Theriault, McNamee and Butterfield.[7] Eldridge [8] has shown that with dilutions of sterile material the quantity of seed affects the results obtained. With small amounts of seed there is apparently a lag in the development of the organisms, while with the optimum amount of seed, or more, correct results may be obtained. Holderby and Lea [9] have shown that it is not possible to get correct oxygen demand results on samples in which the organic carbon to nitrogen ratio is greater than 6 to 1. If higher ratios of carbon to nitrogen are present, low oxygen demand results are obtained. To correct the nitrogen deficiency in samples of this character, Lea and Nichols [10, 11] propose the use of the sodium bicarbonate water supplemented by the addition of phosphate and ammonia. Such a dilution water is necessary for determining the B.O.D. of paper mill wastes and is probably not objectionable in most sewage and polluted water work unless long time demands are to be obtained. Data from our laboratory indicate that with activated sludge effluents, high results may be obtained during the five day incubation period as a result of the oxidation of the nitrogen added to the dilution water.

Interpretation of the Results of the Oxygen Demand Test

The general form of the deoxygenation curve has been given for three temperatures (9, 20 and 30° C.) by Theriault.[1] At 20° C., a marked increase in rate of oxygen utilization was noted about the 14th day indicating the start of the second stage of oxidation. At the higher temperature the practical completion of the carbonaceous oxidation

was earlier while at the lower temperature the completion of the carbonaceous oxidation was delayed and the second stage had not started at the end of the experiment. It has been established that the first stage oxidation reaction follows a definite mathematical rate.

The mathematical expression of this rate is very useful in the practical interpretation of the analytical results. It has been found that the rate of oxidation at any instant is directly proportional to the amount of organic matter present in the sample. The mathematical expression for this when the organic matter is given in terms of oxygen demand is

$$X_t = L(1 - 10^{-kt}) \tag{1}$$

where

X_t = the oxygen demand in t days,
L = the total oxygen demand of the first stage,
k = deoxygenation velocity constant = 0.10 at 20° C.

The deoxygenation velocity constant k varies with the temperature and can be calculated for any temperature from the relation

$$k_T = k_{20}(1.047^{T-20}) \tag{2}$$

where

k_T = deoxygenation velocity constant at T° C.
k_{20} = deoxygenation velocity constant at 20° C. = 0.10.

The total oxygen demand (L) for the first stage also varies with the temperature. The expression for this relationship is:

$$L_T = L_{20}(0.02T + 0.60) \tag{3}$$

where

L_T = value of L at T° C.
L_{20} = value of L at 20° C.

With the help of these three formulae the oxygen demand (first stage) of a sample for any temperature and any time period may be calculated from a laboratory oxygen demand test. Tables are available in the literature to assist in these calculations. Phelps [12] has presented a table of factors for the conversion of the 5-day B.O.D. at 20° C. to the demand for any other time and temperature. In the preparation of this table the change in total demand (L) for changes in temperature has been disregarded. However, this change is not great for small divergences from 20° C. and consequently for practical purposes these factors are very useful. Theriault [2] presented a series of tables of the values of the function $(1 - 10^{-kt})$ for incubation times up to 25 days and for various values of k from .040 to .250. Streeter [13] has contributed a table of the values of the deoxygenation velocity coefficient for all temperatures from 0 to 30° C. calculated from formula.[2] Hoskins [14] has illustrated the oxygen demand computations using these three formulae and presented a table of factors for converting the

B.O.D. for any time at 20° C. to any other time at the same temperature.

The course of the second stage or nitrogenous oxidation has not as yet been so well established. Mohlman, et al [15] have presented data on nitrogenous oxidation in the Illinois River. Streeter [13] found that the following discontinuous equation gave excellent fitting with the Illinois River first and second stage oxidation curves.

$$Y = L_c(1 - 10^{-k_c t}) + L_n[1 - 10^{-k_n(t-a)}]$$

where

Y = the total B.O.D. oxidized up to any time (t),
L_c and L_n = the total first and second stage B.O.D. respectively,
k_c and k_n = the deoxygenation coefficients for the first and second stage respectively,

and

(a) = a lag constant indicating the time at which the second stage begins.

In this analysis of the Illinois River data it was found that the oxidation rate for the second stage or nitrogenous oxidation was approximately one-third of the rate for the first stage oxidation, the mean values for k_c and k_n being .103 and .031 respectively.

Biochemical Oxidation in Sewage Treatment

The biochemical oxidation process that has so far been considered occurs under natural conditions. In complete sewage treatment projects some type of biochemical oxidation process such as one of the various sewage filters or the activated sludge method is usually used. In all of these processes the growth of oxidizing bacteria is artificially fostered and the time required for the purification of the sewage is very much shortened. In the activated sludge process, however, it has always been considered that the greater part of the total purification was accounted for by a clarification due to the contact with the sludge and that the biochemical oxidation in the process followed the normal oxidation rates just discussed.

Bacterial Mechanism of the Process

There have been many difficulties which have prevented a satisfactory explanation of the activated sludge mechanism. While considerable progress has been made during the past few years, the complete answer has not yet been obtained. The biological nature of the sludge has been realized for many years. More recently Butterfield [16] has isolated zoogleal bacteria from activated sludge and has grown them in pure culture. These bacteria produce an abundant floc simulating activated sludge. Such pure culture activated sludges have been produced from synthetic sewages in which all food is in true solution. This indicates that this floc production is the result of a synthesis of materials from solution by bacterial multiplication rather than a simple

precipitation or coagulation of colloidal particles. Furthermore, this pure culture sludge floc simulates activated sludge in its ability to purify sewage.

Normal activated sludge apparently contains a considerable proportion of similar zoogleal flocs. These zoogleal flocs present in activated sludge represent tremendous numbers of individual bacterial cells. The total numbers cannot be estimated by ordinary methods because of the difficulties involved in dispersing the flocs so that an enumeration can be made. The enormous numbers of various bacteria which constitute the flocs of activated sludge are apparently the motivating agent in the process. These colonies of bacteria adsorb organic material in solution and in colloidal form and then partially oxidize and partially synthesize this material into new colonies or flocs of bacteria.

Biochemical Oxidation Rates with Activated Sludge

The method used for following the course of biochemical oxidation in activated sludge mixtures has been described.[18] Briefly this is accomplished by aeration of the activated sludge mixture in a completely closed aeration bottle and by analysis of gas samples for oxygen remaining in the system at the desired intervals of time.

An analysis of the data obtained in this way on more than 100 samples of activated sludge taken from a small plant yielded the following results:

(1) The rates seemed to vary considerably.

(2) Data on some samples could be fitted approximately to the unimolecular expression used to represent natural oxidation. In these cases, however, the deoxygenation coefficients had a mean value of .208 indicating that for the periods of observation this oxidation reaction took place at about twice the natural rate.

(3) Data for most of the experiments best fitted the expression:

$$Y = L - [a(10^{-k_1 t}) + b(10^{-k_2 t})].$$

The oxygen utilized at any time (Y) represents the sum of two unimolecular reactions of the type used to represent the natural biochemical oxidation reaction. In these cases the deoxygenation coefficients (k_1) largely representing the oxidation velocity during the first two or three hours of the process were 2.0 to 3.0. These coefficients indicate oxidation velocities from 20 to 30 times natural oxidation.

(4) All data indicated that the oxidation velocity in activated sludge for the periods ordinarily used in actual practice was very much greater than that occurring in natural biochemical oxidation.

(5) With the temperature constant the rate of oxidation was apparently dependent upon the quantity or strength (B.O.D.) of sewage added and upon the condition of the sludge at the time of addition.

Consequently in our later studies we have always included oxygen utilization observations made simultaneously on two similar portions

of activated sludge. One portion (A) contained the sludge under examination with its supernatant replaced with dilution water, to be used as a blank. The second portion (B) contained exactly the same quantity of sludge as (A) but with a similar portion of the supernatant liquor withdrawn and replaced by a fresh sewage as food.

The quantity of oxygen utilized by the sludge as a result of the addition of the food is obtained from the difference of the quantities used in $B - A$. This difference $B - A$ is ascribed to the oxidation of the sewage added. The B.O.D. of the added sewage is determined separately by the dilution method. The oxygen increment ($B - A$) representing the oxidation of the sewage is calculated in percentage of the B.O.D. of the sewage. The rates of oxidation of sewage by both pure culture and normal activated sludge have been obtained in this way.[16, 17, 18]

Biochemical Oxidation as a Measure of Activated Sludge Condition

These studies have indicated that a good activated sludge has a definite optimum range in its oxygen requirement. If an activated sludge is underdosed or starved and/or overaerated, the oxidation rate slowly falls to the natural biochemical oxidation rate. During this time the B.O.D. of the sludge has been reduced but something more important to the success of the process has occurred; the rapid oxidation capacity of the sludge is lost. That is the sludge has a lower capacity to oxidize new food that is given to it. If an activated sludge is overdosed and/or underaerated the oxygen requirement of the sludge itself is slowly increased. In this case its capacity to oxidize new food material at high rates is also reduced. Consequently an important criterion of the biochemical condition of a sludge is the quantity of oxygen required by the mixed sludge liquor or sludge alone when it is returned to the influent end of an aeration tank.

The work has shown definitely that poor activated sludges do not have a greatly increased demand for oxygen during the first three to four hours when dosed with sewage while good activated sludges do. Consequently the comparison of the biochemical oxidation activity of a sludge in an undosed and a sewage dosed mixture as has been described is an important criterion of the condition of a sludge. This observation is of value even if the increased oxygen consumption due to the addition of the sewage should not prove to be an absolutely correct measure of the oxidation of the sewage by the sludge.

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II. THE PSEUDO-PLASTIC PROPERTIES OF SEWAGE SLUDGES

By W. D. Hatfield

Superintendent, Sanitary District, Decatur, Illinois

In a previous article * the author presented a rotational viscometer method for studying the apparent viscosity or flow characteristics of sludges. The flow of sludge was found to be pseudo-plastic and thixotropic thus greatly complicating the flowing properties. The original article referred to Merkel's † work with Imhoff sludges at Stuttgart, Germany, in which he made flow studies both with a rotational viscometer and in 20 cm. (7.87 in.) pipes. This reference was to a resumé in English which was published in *Physics*. Since that time I have had available Merkel's original publication "Die Fliesseigenschaften von Abwasserschlamm," Beiheft Zum Gesundheits-Ingenieur, Reihe II, Heft 14 (1934). This second article is presented to give wider distribution to some of Merkel's splendid data and particularly to use his data for calculating the viscosities of the Stuttgart sludges, as was done with the Calumet data in the first article.

The viscometer data which I presented confirms that of Merkel's and extends the work to raw, separate digestion and activated sludges. The rotational viscometer data when plotted on a shear-stress diagram clearly show the flow characteristics of sludges, but the data are not directly transferable to the equations of flow because the flow is a function of the Reynolds Number and the Reynolds Number is dependent on the diameter of the pipe, the velocity and the viscosity, dimensions which are not comparable between viscometer and pipe.

In general, the viscometer data show that with thick sludges flowing at low velocities the viscosities range from 1000 to 5000 centipoises; at moderate velocities from 100 to 1000 centipoises; and at turbulent velocities from 25 to 100 centipoises. But the designing engineer may ask, "What is the viscosity of a certain sludge of about 10 per cent solids flowing in an 8-in. pipe at some definite velocity?" If such data could be calculated, even though only approximately accurate, the data would be of inestimable value in the design of sludge handling equipment and pipe lines.

To help answer these questions Merkel plotted his excellent studies of the flow of digested sludge in 20 cm. pipe lines at Stuttgart. I have reproduced in Figure 1 his data which I have traced from his Figure 26 on page 23 of the reference given above. In this figure the velocity of flow in meters per second is plotted against the loss of head in meters per meter, obtained in 20 cm. (7.87 in.) pipes. The sludge is described by Merkel as half digested sludge containing from 84 to 91 per cent moisture.

* W. D. Hatfield, This Journal, **10**, 1, Jan., 1938.
† Wilhelm Merkel, *Physics*, **5**, 355–361 (1934).

The striking similarity between the curves of this Figure 1 and those of Figure 5, page 16, of the original article is at once apparent, showing that the flow in pipes follows the same general curve obtained by the

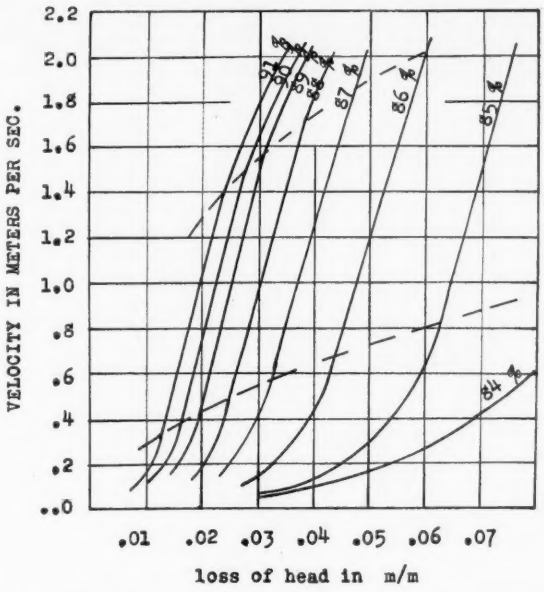

FIG. 1.—Loss of head in 20 cm. pipe at Stuttgart from Merkel's Figure 26.

TABLE I.—*Viscosity of Stuttgart Sludges Calculated from Data in Figure I Which was Reproduced from Wilhelm Merkel's Work. Diameter of Pipe 20 Cm (7.87 in.)*

Head Loss ΔH ft./ft.	Moisture Content of Sludge													
	84%		85%		86%		87%		88%		89%		90%	
	u ft./sec.	Z cp.	u ft./sec.	Z cp.	u ft./sec.	Z cp.	u ft./sec.	Z cp.	u ft./sec.	Z cp.	u ft./sec.	Z cp.	u ft./sec.	Z cp.
0.010													0.36	1170
.0156											0.66	1000		
.02									0.66	1300	1.51	560	2.46	344
.0244							0.66	1595						
.03	0.197	7020	0.26	5160	0.49	2640	1.35	960	3.15	405	4.93	258	5.55	228
.035													6.35	200
.038											6.56	242		
.04	0.328	5600	0.46	3910	1.48	1170	4.03	426	6.05	281				
.042									6.56	266				
.05	0.525	4400	0.91	2460	3.91	556	7.03	305						
.06	0.92	3020	2.13	1265	6.67	390								
.07	1.41	2390	4.93	640										
.08	2.04	1810												

flow in the viscometer. The velocity and loss of head data were taken off Figure 1 and applied in calculating the viscosities, as was done with the Calumet data, by using the equation

$$\Delta H_f D/u^2 L = \phi\,(Dup/(Z/1488)) = 2f/g,$$

with one of the familiar forms of the Reynolds-Straton diagrams. The velocities and corresponding calculated viscosities are tabulated in Table I.

These calculated viscosities on the Stuttgart sludges are very similar in range to viscosities of the Decatur sludges obtained in the vis-

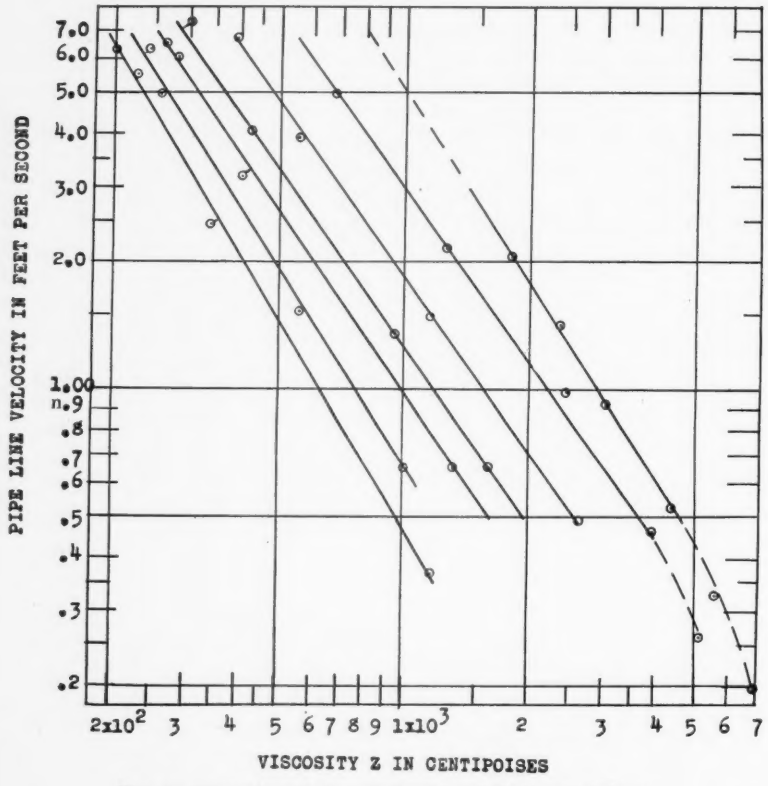

FIG. 2.—Viscosity-velocity relationship of Stuttgart sludges.

cometer and tabulated in Table II, page 14, of the original article. For example, the Decatur sludge No. I, with a moisture content of 85.38 per cent, had a viscosity range from 690 to 5400 in the viscometer; the Stuttgart sludge, with a moisture content of 85 per cent, had calculated viscosities ranging from 640 to 5160 centipoises. In Figure 2 these calculated viscosities of the Stuttgart sludges are plotted against the velocity, as was done in Figure 6, page 19 (on logarithmic coordinates), expressing the velocity in feet per second. Parallel lines are again ob-

tained with a *negative* slope of 1.4 to 1.6, thus checking with the more concentrated sludges from Springfield and Decatur which produced the same slope from viscometer data, where the velocity is expressed in revolutions per second.

It would appear that the use of the fluid flow equations for the flow of sewage sludges is further substantiated, at least until a more accurate equation is formulated.

Summary

These data, with those presented previously, may be summarized as follows: (1) quiescent thick sludges will have viscosities of 3000 to 5000 centipoises at very low rates of flow, (2) as the velocities increase the viscosities will decrease to 200 to 300 centipoises, (3) at turbulent flow the viscosities may drop below 100 centipoises and (4) from these viscosity ranges the loss of head or pressure drop may be approximately calculated.

Correction: Viscosity or Pseudo-plastic Properties of Sewage Sludges. This Journal, **10**, page 18, line 6. Revolutions per minute should read revolutions per second.

EXPERIMENTAL WORK IN PROGRESS AT THE WEST SIDE SEWAGE TREATMENT WORKS OF THE SANITARY DISTRICT OF CHICAGO *

By T. L. Herrick

Asst. Civil Engineer, The Sanitary District of Chicago

During the past two years the Sanitary District of Chicago has operated several experimental units which were designed to study the treatment of Imhoff tank effluent. This paper will be confined to the description of these units and a brief discussion of operating results. All of the units are located at the West Side Sewage Treatment Works.

The experimental units included are:

1. A high rate trickling filter.
2. A process in which sewage was aerated in the presence of rubber sponges, with a small scale activated sludge unit operated in parallel.
3. A two-stage bio-filter.
4. A chemical precipitation plant with a plain settling unit operated in parallel, both units followed by fine grained filters.
5. An activated sludge unit designed to operate under very low aeration periods.

High Rate Trickling Filter

This unit was laid out and built in accordance with suggestions and recommendations of Dr. H. O. Halvorson of the University of Minnesota and Mr. William Buckley of the Simplex Ejector and Aerator Corporation, Chicago (Fig. 1). Their recommendations concerning operation have also been followed.

This unit was constructed during the summer of 1935 and was placed in operation in September of that year. The filter is contained in a circular wooden tank 20 ft. in diameter and 9½ ft. deep. The stone is supported by 2 in. by 2 in. timbers with 1 in. clear openings between them. They are supported on 3 in. by 8 in. timbers placed on edge 18 in. center to center. A slope of approximately ¼ in. per foot is provided in the bottom of the tank to the draw-off at the center.

The filtering medium is crushed limestone from a local quarry. The depth of stone is 8 feet. Results of 12 sieve analyses are shown in the table below.

Diameter of Hole, Inches	Per Cent Retained
3	23.8
2½	38.5
2	25.7
1½	10.0
1	2.0

* Presented at the Fifty-third Annual Meeting of the Illinois Society of Engineers, Peoria, Ill., Jan. 28, 1938.

Imhoff effluent is applied continuously to the bed by means of a Simplex rotary distributor with four arms, with four nozzles on each arm. Until October 29, 1937, a nozzle with an adjustable flap was used. These nozzles provided a wide, flat spray. On the above date nozzles of a new type, made of vitrified clay were installed. The sewage leaves this nozzle with a whirling motion, which results in a rain-like application to the bed.

Provision is made for artificial aeration of the stone. A 4 in. pipe with an open end located under the stone at the center of the tank is connected to the suction of a fan. Thus air may be drawn down

FIG. 1.—High-rate trickling filter (Halvorson).

through the stone. When the fan is not in use air is admitted under the stone through a series of 2 in. holes on 20 in. centers drilled around the tanks.

The settling tank is 12 ft. in diameter and 11 ft. deep. A hopper bottom is provided with the slope 1.36 vertical to 1.0 horizontal. The sludge removed is measured in batches in a box. The effluent trough is located inside the tank and is fitted with a notched overflow weir. Provision is made for wasting a portion of the filter effluent in order that the settling period may be varied.

A small centrifugal pump is provided for recirculating final effluent through the filter.

Imhoff tank effluent is pumped to the unit by means of a centrifugal pump. Originally the flow was measured by means of a constant head orifice box. This was replaced late in 1937 by a 3 in. by 1½ in. venturi tube.

The unit was placed in service September 11, 1935. It has operated continuously since that time, except for two short intervals.

General operating data and results of analyses for suspended solids and 5-day B.O.D. are shown in Table I. The dosing rate has been

TABLE I.—*High-rate Trickling Filter*
Operating Data and Results of Analyses

Month 1935–36–37	Dosing Rate, M.G.A.D.	Detention Period in Settling Tanks, Hrs.	5-day B.O.D., p.p.m.			Suspended Solids, p.p.m.		
			Raw Sewage	Influent to Filter	Settling Tank Effluent	Raw Sewage	Influent to Filter	Settling Tank Effluent
September 11–30	20.2	0.85	82	36.2	14.8	120	40	20
October	20.2	0.84	121	47.2	18.6	183	52	22
November	20.2	0.84	97	44.5	27.7	120	43	28
December	20.2	0.85	118	66.2	35.6	119	53	28
January	20.2	0.84	130	59.3	28.5	128	42	24
February	20.2	0.99	150	74.5	43.9	158	60	36
March	20.2	1.0	54	30.9	16.3	74	35	19
April	20.2	1.0	95	52.7	23.5	124	54	30
May 8–31	20.2	1.0	96	49.3	27.2	142	56	44
June	20.2	1.0	82	46.8	25.5	100	50	30
July	20.2	1.0	63	34.7	17.2	89	35	23
August	20.2	1.1	79	28.1	13.3	102	38	23
Average	20.2	0.94	97	47.6	24.3	122	47	27
September	26.6	1.5	71	26.6	12.3	107	38	16
October	26.6	1.5	85	38.9	21.7	106	39	17
November	26.6	1.5	98	48.2	25.9	125	53	23
December	26.6	1.5	96	70.5	29.3	128	59	31
January	26.6	1.5	80	66	26.6	82	66	32
February	26.6	1.5	91	77	33.0	98	73	39
March	26.6	1.2	98	80	26.0	121	64	33
April	26.6	1.3	97	62	20.6	130	69	28
May	26.6	1.2	102	64	29.2	120	79	29
June	26.7	1.3	104	75	38.7	138	89	42
Average	26.6	1.4	92	61	26.3	116	63	29
July	30.0	1.1	90	66	23.6	125	77	22
August	30.0	1.0	87	52	27.6	99	59	27
September	28.8	1.1	87	62	26.6	104	65	22
October 1–17	23.0	1.9	97	66	26.6	110	75	21
November 4–30	30.0	1.5	106	88	43.4	105	78	32
December	30.0	1.2	106	110	51.7	105	90	40
Average	28.6	1.3	96	74	33.2	108	74	27

Note: Fan used September 20 to December 13, 1935, and from May 15 to July 31, 1936, at a rate of 1 cu. ft. per minute per square foot. Effluent was recirculated September 13, 1935 to February 2, 1936. The amount returned was 15 per cent of the influent.

varied from 20.2 to 30.0 M.G.A.D. and the settling period from 0.84 to 1.9 hours.

In Table II are shown nitrogen determinations on influent and settled filter effluent. The per cent reduction of organic nitrogen appears to be as great with the higher rates as with the lower.

TABLE II.—*High-Rate Trickling Filter Nitrogen Determinations*, p.p.m.

Month 1935–36–37	Influent to Filter		Final Effluent			
	Org.	Amm.	Org.	Amm.	Nitrite	Nitrate
September 11–30	6.0	11.4	4.1	10.5	0.6	0.2
October	5.1	10.0	3.7	8.7	0.5	0.6
November	6.0	9.2	3.9	8.0	1.0	1.2
December	5.9	12.1	4.0	10.6	0.9	1.3
January	5.5	13.8	3.8	13.2	0.4	0.6
February	5.8	12.8	4.8	12.3	0.1	0.6
March	4.8	6.5	3.3	6.2	0.3	0.8
April	12.1	6.1	7.2	6.8	0.1	0.3
May 8–31	9.5	6.5	6.8	6.2	0.9	0.2
June	9.2	8.3	5.5	6.5	2.2	0.4
July	6.4	6.6	3.6	4.0	1.1	2.3
August	7.5	7.8	3.4	3.1	0.9	2.5
Average	7.0	9.3	4.5	8.0	0.8	0.9
September	7.3	5.1	4.6	1.9	0.4	3.7
October	8.5	8.0	3.6	4.3	0.3	4.0
November	6.9	8.4	3.8	5.1	0.3	3.7
December	10.1	7.9	6.5	7.2	0.2	1.6
January	9.7	6.5	5.8	6.7	0.2	2.0
February	10.2	7.0	8.1	7.9	0.1	0.6
March	8.8	7.0	6.5	8.5	0.1	0.6
April	8.4	6.1	4.8	8.0	0.2	0.4
May	8.9	7.6	7.2	8.8	0.1	0.7
June	9.5	8.8	6.5	7.5	0.4	1.5
Average	8.8	7.2	5.7	6.6	0.2	1.9
July	7.8	6.2	3.1	4.9	0.7	1.7
August	7.8	8.2	4.6	4.4	0.6	3.1
September	7.0	7.2	4.1	4.1	0.4	3.0
October 1–17	6.8	8.8	3.0	5.0	0.4	2.2
November 4–30	9.4	10.4	6.1	7.4	0.4	1.2
December	10.1	9.1	5.6	8.6	0.2	1.1
Average	8.2	8.3	4.4	5.7	0.4	2.0

Table III gives data on removal of suspended solids and 5 day B.O.D. There is a slight falling off in the overall per cent reduction of B.O.D. as the dosing rates increased. However, there is a great increase in the B.O.D. removal as expressed in pounds per acre per day.

The filter has operated at these high rates with no evidence of clogging. Apparently even higher rates of dosage may be employed.

TABLE III.—*High-Rate Trickling Filter*
Removal of 5-Day B.O.D. and Suspended Solids

Month 1935–1936 1937	5-day B.O.D.						Suspended Solids			
	Parts per Million Removed by		Per Cent Reduction		Removal in Pounds per Day by Filter plus Settling Tank		Parts per Million Removed by		Per Cent Reduction	
	Imhoff Tanks	Filter plus Sett. Tk.	Raw to Imhoff Efflu-ent	Raw to Final Efflu-ent	Per Acre	Per Acre per Foot	Imhoff Tanks	Filter plus Sett. Tk.	Raw to Imhoff Efflu-ent	Raw to Final Efflu-ent
September 11–30	45.8	21.4	55.9	82.0	3,600	450	80	20	66.7	83.3
October	73.5	28.9	60.7	84.7	4,870	609	131	30	71.6	88.0
November	52.5	16.8	43.8	71.5	2,827	354	77	15	64.2	76.7
December	51.8	30.6	43.9	69.8	5,150	644	66	25	55.5	76.5
January	70.7	30.8	54.4	78.0	5,190	649	86	18	67.2	81.3
February	75.5	30.6	50.3	70.8	5,150	644	98	24	62.0	77.2
March	23.1	14.6	42.8	70.0	2,457	307	39	16	52.7	74.3
April	42.3	29.2	44.6	75.3	4,914	614	70	24	56.4	75.7
May 8–31	46.7	22.1	48.7	71.7	3,719	465	86	12	60.5	69.0
June	35.2	21.3	42.9	69.0	3,585	448	50	20	50.0	70.0
July	28.3	17.5	45.0	72.8	2,945	368	54	12	60.6	73.8
August	50.9	14.8	64.4	83.2	2,491	311	64	15	62.7	77.5
Average	—	—	49.8	74.9	3,908	488	—	—	60.8	77.0
September	44.4	14.3	62.5	82.7	3,170	396	69	22	64.5	85.0
October	46.1	17.2	54.4	74.5	3,816	477	67	22	62.8	83.9
November	49.8	22.3	50.8	73.6	4,947	618	72	30	50.8	82.0
December	25.5	41.2	26.6	69.5	9,140	1142	69	28	53.9	75.8
January	14	39.4	17.1	66.8	8,741	1092	16	34	19.5	61.0
February	14	44.0	15.4	63.7	9,761	1220	25	34	25.5	60.2
March	18	54.0	18.4	73.5	11,979	1497	57	31	47.0	72.8
April	35	41.4	36.1	78.7	9,184	1148	61	41	47.0	78.5
May	38	34.8	36.3	71.4	7,720	965	41	50	34.2	75.8
June	29	36.3	27.8	62.7	8,083	1010	49	47	35.5	69.5
Average	—	—	34.5	71.7	7,654	956	—	—	44.1	74.4
July	24	42.4	26.7	73.8	10,608	1326	48	55	38.4	82.4
August	35	24.4	40.2	68.3	6,105	763	40	32	40.5	72.8
September	25	35.4	28.7	69.4	8,503	1063	39	43	37.5	78.8
October 1–17	31	39.4	32.0	72.6	7,558	945	35	54	31.8	80.9
November 4–30	18	44.6	17.0	59.0	11,159	1395	27	56	25.7	69.5
December	—	58.3	—	51.2	14,586	1823	15	50	14.3	61.9
Average	—	—	24.1	65.7	9,753	1219	—	—	31.4	74.4

Filter flies have not been troublesome. They appear to develop in the stone but do not come to the surface unless the flow is shut off for some reason. During the late summer dead flies have been noted coming through to the settling tank.

Tests on the unit are to be continued. It is contemplated building a small rapid sand filter to study further treatment of the settling tank effluent.

Sponge Aeration Process and Activated Sludge

Early in 1936 an experimental plant was constructed in which sewage was aerated in the presence of sponge rubber blocks. A small scale activated sludge unit was built to operate in parallel. The use of sponge rubber blocks was originated by A. L. Tholin, then an Assistant Civil Engineer with the Sanitary District. Although these tests have been completed they should be mentioned briefly.

The aeration tanks for the two units were formed by dividing a rectangular wooden tank into two bays, each bay being 11 ft. 4 in. long, 2 ft. 6 in. wide, with a water depth over the diffuser plates of 4 ft. 2 in. Standard 12-in. by 12-in. diffuser plates were used, but a portion of each plate was blanked off.

A hopper-bottom settling tank was provided for each unit. Each tank was 6 ft. outside diameter with a water depth of 5 ft. 2 in. The slope of the hopper was 1.36 vertical to 1.0 horizontal.

The return sludge in the activated sludge unit was pumped by means of a small air lift. The sludge was measured by means of a 90-degree V-notch weir and discharged into an open trough leading to the influent end of the aeration tank.

As with the high rate filter, Imhoff tank effluent was used to operate the unit. The influent was measured by means of a constant-head orifice box.

The unit was placed in operation April 1, 1936. The first rubber used consisted of 12.6 cu. ft. of material cut into 2000 2 in. cubes. 1000 2 in. by 2 in. by 1 in. blocks with 1 in. diameter holes (plugs also added), and 72 pieces of 4¾ in. in diameter and 1½ in. thick with a 2 in. hole.

The large pieces and many of the 2 in. cubes did not circulate well. During the first week the large pieces were cut into four pieces and during the second week the 2 in. cubes were cut into 1 in. cubes. The rubber was used in this condition until July 15 when it was removed and discarded. The pores in the sponge rubber had become filled with solids, and the pieces were too heavy to circulate with the spiral flow. New rubber was placed in the tank July 19. This material consisted of 110,000 pieces in the form of ½ in. cubes. It was used during the balance of the tests.

In March, 1937, the aeration tank was altered by the addition of a cage for holding the sponges directly over the diffuser plates. The sewage passed upward through the sponges and downward outside the cage, thus giving a multi-stage process. The tank was used in this condition until the test was discontinued in November, 1937.

Very few changes were made in the activated sludge unit. The unit was out of service from July 15 to September 15, 1936, during which time the tanks were used for another test. The tests on activated sludge were discontinued July 31, 1937.

TABLE IV.—*Sponge Aeration Process and Activated Sludge*
General Operating Data

Month 1936–1937	Aeration Period, Hours		Air Used, Cu. Ft. per Gallon		Activated Sludge Unit	
	Activated Sludge	Sponge Process	Activated Sludge	Sponge Process	% Solids Aeration Mixture	Sludge Index (30 Min. Settling)
April	2.9	3.4	0.72	1.46	.154	62
May	2.9	3.4	0.50	1.46	.131	98
June	2.0	2.3	0.47	1.49	.122	113
July 1–15	2.0	2.3	0.47	1.63	.106	154
August	—	2.3	—	0.80	—	—
September	—	2.3	—	0.79	—	—
October	1.0	1.1	0.38	0.57	.182	63
November	1.1	1.1	0.38	1.05	.159	57
December	1.1	1.4	0.38	0.50	.160	48
January	—	2.3	—	1.28	—	—
January 1–12	1.1	—	0.38	—	.184	39
January 13–31	2.2	—	0.76	—	.238	44
February	2.2	—	0.55	1.28	.213	49
March 1–11	—	2.4	—	1.28	—	—
March 1–21	2.4	—	0.42	—	.175	56
April 11–30	1.6	2.4	0.32	0.65	.190	48
May	1.6	2.3	0.32	1.19	.162	70
June	1.6	2.3	0.32	1.19	.154	73
July	1.6	2.3	0.32	1.19	.125	97

In Table IV monthly averages are given for aeration period and air consumption in each unit; and for aeration mixture per cent solids and sludge index for the activated sludge unit.

Table V shows monthly average analysis for 5 day B.O.D. and suspended solids. It will be noted that the activated sludge unit gave an excellent affluent with aeration periods as low as 1.6 hours. The effluent obtained with a period of 1.1 hours, though somewhat inferior, was better than obtained in the high rate filter for the same period.

TWO-STAGE BIO-FILTER

This plant was built in accordance with the recommendations of Mr. Harry N. Jenks of Berkeley, California. The unit is similar to plants built by Mr. Jenks in the west.

Construction work, except for erection of tanks, was done by Sanitary District forces during the late summer and fall of 1936. Two stages of treatment are provided, each of which includes a circular filter bed, a hopper bottom detention tank, a pump for recirculating effluent and metering and control equipment (Fig. 2).

The plant is laid out with the centers of the filters and tanks at the corner of a rectangle 20 by 20½ feet. A concrete sump for each stage

TABLE V.—*Sponge Aeration Process and Activated Sludge Results and Analyses*

Month 1936–1937	5-day B.O.D.					Suspended Solids				
	Influent, p.p.m.	Effluent, p.p.m.		Per Cent Reduction		Influent, p.p.m.	Effluent, p.p.m.		Per Cent Reduction	
		Activated Sludge	Sponge Process	Activated Sludge	Sponge Process		Activated Sludge	Sponge Process	Activated Sludge	Sponge Process
April	52.4	10.2	16.0	80.5	69.5	53	16	21	81.1	60.4
May 8–31	49.3	11.5	17.4	77.7	64.7	56	14	17	75.0	69.6
June	46.8	15.1	30.6	67.8	34.6	50	8	16	84.0	68.0
July 1–15	37.0	4.6	10.3	87.6	72.2	36	5	11	86.1	69.4
August	28.1	—	16.9	—	39.9	38	—	18	—	52.6
September	26.6	—	11.7	—	56.0	38	—	19	—	50.0
October	38.9	15.7	31.0	59.6	20.3	39	20	28	48.7	28.2
November	46.7	21.1	38.1	54.8	18.4	51	26	35	49.0	31.4
December	70.5	25.9	54.6	63.3	28.8	59	27	51	54.2	12.1
January	74.7	—	44.2	—	36.8	65	—	35	—	50.0
January 1–12	57.2	13.1	—	77.0	—	70	15	—	78.5	—
January 13–31	74.7	13.4	—	82.0	—	65	15	—	77.0	—
February	77	11.2	39.3	85.5	49.0	73	11	41	84.9	43.8
March 1–11	84	—	48.0	—	42.8	64	—	41	—	36.0
March 1–21	85	10.1	—	88.2	—	67	11	—	83.6	—
April 11–30	60	13.9	35.1	77.0	41.5	64	15	31	76.6	51.5
May	64	15.1	38.2	76.4	40.3	79	18	30	77.2	62.0
June	75	16.8	36.4	77.6	51.1	89	22	38	75.3	57.3
July	66	14.1	22.1	78.6	66.5	77	15	23	80.5	70.1

and a pump well for the two pumps is located between the tanks. Each sump is 2 ft. by 2½ ft. in plan and 4½ ft. deep. A stop log is provided between the sumps. The pump well is 4 ft. by 5 ft. in plan and 2½ ft.

FIG. 2.—Two-stage high rate filter (Jenks).

deep. The pumps are belt driven by motor mounted on the wall of the pump well. The sumps and pump well are housed in, the tanks forming two sides of the housing.

Each filter is 15 ft. in diameter with 3 ft. of stone. The stone is supported by 2 in. by 2 in. strips with 1 in. clear openings laid across 2 in. by 8 in. timbers on edge, 2 ft. center to center. The outer shell of the filters are No. 18 gauge galvanized, corrugated sheet metal. An inner ring of No. 18 gauge sheet metal 8 ft. 8 in. in diameter is provided forming two zones, with the area of the outer twice that of the inner. This permits greater flexibility in rate of dosing and in length of detention period in the tanks.

A rotary distributor is provided on each filter for applying the sewage to the stone. There are four arms on each distributor with six outlets in each arm. Originally arms with ¾ in. holes without nozzles or sprays of any kind were used. The holes were staggered from arm to arm. In April, 1937, new arms with spreaders were installed. The distributors were made in the Sanitary District shops.

The stone for the filters was obtained from local quarries. The stone for the primary stage filter is for the most part between the sizes of 1½ inches and 2½ inches as shown by the following analysis.

Diameter of Hole, Inches	Per Cent Retained
2½	10.4
2	37.2
1½	46.5
1	5.9

The stone for the secondary filter is quite small in size, as shown by the following analysis.

Diameter of Hole, Inches	Per Cent Retained
1½	0.0
1	74.0
¾	24.7
	1.3 (passing ¾ in.)

The detention tanks are built of wood and have hopper bottoms. Each tank is equipped with a 4 in. influent line from its recirculating pump, a 4 in. effluent line, a 6 in. recirculating line and a 3 in. sludge draw-off line. A weir trough is located around the inside periphery of each tank at the top. The weirs are made of galvanized sheet metal.

The tank for the primary stage tank is 10 ft. outside diameter with a water depth of 11 ft. A slope of 1.94 vertical to 1.0 horizontal is provided in the hopper.

A return sludge line is provided in the first stage only. A 2½ in. line leads from the 3 in. sludge draw-off line to the influent line leading to primary filter.

The secondary stage tank is 14 ft. outside diameter with a water depth of 11 ft. The slope of the hopper is 1.73 vertical to 1.0 horizontal.

The influent to the unit is metered by means of a flow nozzle. Venturi tubes are provided on the pump discharge lines for metering the quantity passing through the filters.

In operation the influent passes directly to the primary filter. The filter effluent flows to a sump from which it is pumped to the settling-detention tank. A portion of the effluent from this tank is mixed with the incoming sewage and passes through the filter a second time. The remainder of the effluent is passed to the secondary filter where the process is repeated.

Operating data covering the period from the start of the test through 1937 are given in Tables VI to IX.

TABLE VI.—*Two Stage Bio-Filter*
General Operating Data

Month 1936–1937	Influent Flow, G.P.M.	* Rate of Filtration, M.G.A.D. (on each Filter)	Rate of Recirculation, G.P.M.	Detention Period in Tanks, Hours (Based on Influent Flow)		Settling Rate (Based on Total Flow of Recirculation), Gal./sq. ft./Day	
				Primary	Secondary	Primary	Secondary
December	83	29.8	166	0.77	1.18	3273	1649
January	85	30.1	170	0.76	1.18	3304	1652
February	85	30.0	170	0.76	1.18	3304	1654
March	85	30.3	169	0.76	1.18	3305	1654
April †	82	43.8	170	0.79	1.22	3305	1654
May †	74	39.3	170	0.87	1.35	3305	1654
June 1–9 and 15–23 †	68	36.2	167	0.93	1.44	3240	1620
July	—	—	—	—	—	—	—
August	45	16.0	128	1.44	2.22	2488	1248
September	50	17.8	135	1.33	2.04	2624	1306
October 1–17	67	23.7	136	0.98	1.51	2639	1320
November ‡	48	24.4	96	1.39	2.15	1857	929
December †	45	24.0	90	1.44	2.22	1750	875

* Based on influent flow.

† Only outer zone of each filter used.

‡ Only outer zone of each filter used November 3–30, inc.

The unit was started under very adverse conditions. Cold weather had set in when it was placed in operation and it was started at rather a high dosing rate. The poor conditions for starting the unit were reflected in the results of the first six months of operation. It was thought that the warmer weather in June would bring better results, but such was not the case. Late in June the unit was shut down and the stone allowed to dry for a 20-day period and the biological growth then built up by a "batch" process.

This procedure consisted of circulating the contents of each detention tank through its respective filter. Each morning the tanks were drained and refilled with Imhoff tank effluent. This was repeated for about 18 days. At the end of that time the filter was put into continuous operation with a dosing rate of 16.0 M.G.A.D. on each filter. Results for succeeding months showed marked improvement.

TABLE VII.—*Two-Stage Bio-Filter*
Results of Analyses

Month 1936–1937	5-Day B.O.D., p.p.m.				Suspended Solids, p.p.m.			
	Raw Sewage	Influent to Filter	Bio-Filter		Raw Sewage	Influent to Filter	Bio-Filter	
			Primary Stage Effluent	Final Effluent			Primary Stage Effluent	Final Effluent
December	96	70	70	51	128	59	69	58
January	80	65	59	53	82	65	67	62
February	91	77	62	54	98	73	65	62
March	98	80	77	66	121	64	80	75
April	97	62	67	62	130	69	87	83
May	102	64	62	54	120	79	82	66
June	104	74	43	45	139	93	68	56
July	—	—	—	—	—	—	—	—
August	86	50	34	19	99	59	39	40
September	87	62	35	19	104	65	30	31
October	97	66	53	36	110	75	57	37
November	105	88	68	48	105	77	77	50
December	106	110	51	31	105	90	52	28

There was considerable pooling on both filters during the first few months of operation. During December both filters pooled badly, though the secondary filter cleared up before the end of the month. In January only the primary filter appeared to be clogged, and it cleared

TABLE VIII.—*Two-Stage Bio-Filter*
Removal of 5-Day B.O.D. and Suspended Solids

Month 1936–1937	5-Day B.O.D.						Suspended Solids			
	Parts per Million Removed by		Per Cent Reduction		Lbs. Removed by Bio-Filter		Parts per Million Removed by		Per Cent Reduction	
	Imhoff Tanks	Bio-Filter	Raw to Imhoff Effluent	Raw to Final Effluent	Per Acre per Day	Per Acre per Ft. per Day	Imhoff Tanks	Bio-Filter	Raw to Imhoff Effluent	Raw to Final Effluent
December	26	19	26.6	46.8	2362	787	69	1	53.9	54.7
January	15	12	17.1	33.3	1506	502	17	3	19.5	24.4
February	14	23	15.4	40.7	2877	959	25	11	25.5	36.8
March	18	14	18.4	32.7	1769	590	57	—	47.0	—
April	35	—	36.1	36.1	—	—	61	—	47.0	—
May	38	10	36.3	56.9	1639	546	41	13	34.2	45.0
June	30	29	28.8	56.7	4377	1459	40	37	33.1	59.6
July	—	—	—	—	—	—	—	—	—	—
August	36	31	41.8	78.0	2068	689	40	19	40.5	59.6
September	25	43	28.7	78.1	3191	1064	39	34	37.5	70.2
October	31	30	32.0	62.9	2964	988	35	38	31.8	66.4
November	17	40	16.2	54.3	4070	1357	28	27	25.7	52.4
December	—	79	—	70.8	7906	2635	15	77	14.3	73.3

up before the end of the month. The secondary filter started pooling again in February and continued through March and part of April.

In Table IX are given data on nitrogen determinations. It will be noted that there was practically no nitrification during the period before the filters were built up by the "batch process." The last five months, however, show a decided increase. There is a corresponding increase in reduction of organic nitrogen.

Table VIII shows data on removal of 5-day B.O.D. and suspended solids. The improvement after August 1st should be noted.

The unit will probably be continued in operation for some time in order to note its performance in warm weather.

TABLE IX.—*Two-Stage Bio-Filter*
Nitrogen Determinations

Month 1936–1937	Influent to Filter		Primary Stage Effluent		Final Effluent			
	Organic	Ammonia	Organic	Ammonia	Organic	Ammonia	Nitrate	Nitrate
December	10.1	7.9	7.8	8.2	6.6	8.1	0.1	0.5
January	9.7	6.5	7.6	6.4	7.1	6.9	0.2	0.4
February	10.2	7.0	7.6	8.1	7.0	8.2	—	0.3
March	8.8	7.0	8.3	7.5	8.0	8.2	0.1	0.3
April	8.4	6.1	8.5	6.2	7.6	6.6	0.2	0.4
May	8.9	7.6	8.2	8.0	9.4	7.9	0.2	0.3
June	9.2	9.2	8.0	8.0	5.7	8.8	0.2	0.1
July	—	—	—	—	—	—	—	—
August	7.8	8.2	5.4	5.4	3.8	2.2	1.0	3.2
September	7.0	7.2	4.4	5.1	4.2	1.8	0.6	3.4
October	6.8	8.8	5.8	7.5	4.9	4.9	0.6	1.0
November	9.4	10.4	8.4	8.6	6.4	7.1	0.5	1.8
December	10.1	9.1	6.5	8.3	2.9	5.6	0.7	5.8

CHEMICAL PRECIPITATION

Early in 1937 construction was started on a large scale test plant for chemical precipitation in Imhoff tanks followed by filtration through magnetite filters. A unit for plain Imhoff sedimentation was built as a control. The unit was completed and placed in service early in September, 1937.

One Imhoff tank in Battery C at the West Side Works was chosen for this test. This tank is 80 ft. by 80 ft. in plan with a total water depth of 37 feet. The tank has 6 flowing-through compartments and 2 sludge hoppers. A timber wall was built, dividing the tank into two halves. The wall extends from the ridge between the sludge hoppers up through the central gas vent, just above normal water level in the tank. One-half of the tank is used for plain settling and the other half for settling chemically treated and flocculated sewage.

The settling volume in each half of 15,830 cu. ft. and the sludge volume is 60,400 cu. ft. Each half provides a settling period of one hour at a flow of 2.83 M.G.D.

Raw sewage is supplied to the experimental unit by means of a vertical shaft propeller type pump mounted in a manhole on the influent conduit to Battery C.

A chemical house, 24 ft. by 30 ft. in plan, houses the influent measuring weir, chemical dosing equipment, and storage space for chemicals. The influent channel is 4 ft. 6 in. wide above the measuring weir. Below the weir it divides into two channels, one for plain settled sewage, and the other for chemically treated sewage.

The chemical dosing equipment includes two solution tanks, two pumps, and an orifice box for ferric chloride; a dry feeder for lime, chlorine control apparatus, a dry feeder for copperas, and a solution and contact box for chlorinated copperas.

Each of the two ferric chloride solution tanks is 8 ft. diameter and 8 ft. deep, inside measurements. They are built of 3 in. tank grade

FIG. 3.—Chemical precipitation. Mixing tank in foreground, followed by flocculation tank.

redwood and are of standard wood stave tank construction, except that the hoops are held out from the staves by wood blocks. They were coated inside and out with coal-tar pitch.

Two hard-rubber pumps are provided for pumping the ferric chloride solution to the orifice box. Excess solution flows back to the solution tank.

The ferric chloride is added in a 4 per cent solution to the channel just below the measuring weir. Lime in the hydrated form is added to the channel a short distance below.

From the chemical house the sewage passes into a wooden mixing tank (Fig. 3). This tank is divided into three bays, each bay being 6 ft. wide by 10 ft. long, inside, with a water depth of 7 ft. 4 inches. Air for mixing is diffused through standard 12 in. square diffuser plates. There are 10 plates in each bay.

The mixing period is 5 minutes with three bays in service and with

a one-hour settling period in the Imhoff tanks. The mixing period may be lowered by taking one or two of the bays out of service.

Following the mixing tank there is provided a flocculation tank which is divided into two bays. Each bay is 30 ft. long and 17 ft. 6 in. wide. The water depth is 8 ft. 2 inches. Flocculation equipment consists of paddles mounted on horizontal shafts, three shafts in each bay.

The flocculation period is 30 minutes with a one-hour settling period in the Imhoff tank. Either bay may be taken out of service and the flocculation period thus cut in half.

Between the flocculation tank and the Imhoff tank is a diversion chamber, provided for reversing the flow in the Imhoff tank. A similar chamber is provided for the plain settling unit.

FIG. 4.—Magnetite filters.

Following the Imhoff tank there are provided magnetite filters of the downward flow type (Fig. 4). There is a unit for the plain settled effluent and one for the chemical effluent. Each filter is 120 ft. long and 5 ft. wide, with a sand depth of 3 inches. Provision is made for bypassing a portion of the influent to the filters so that the filtering rate may be varied.

The wash water from the filter for chemically treated sewage is returned to the system ahead of the mixing tanks. Wash water from the other filter is returned ahead of the diversion chamber.

Sludge from either the chemical or plain settling side of the Imhoff tank can be pumped to a sludge drying bed.

The plant was placed in service September 7, 1937. The settling period was held at approximately 1 hour until early in December when

it was changed to 1.5 hours. The magnetite filters have been operated at rates varying from 2.53 to 3.24 gallons per square foot per minute, based on monthly averages.

Only ferric chloride and lime have been used so far, the dosage averaging about 150 pounds of ferric chloride and 200 pounds of lime as calcium oxide per million gallons of sewage.

Activated Sludge Unit

During the summer of 1937 construction was started on an experimental activated sludge unit. As with the filter units the plant operates on Imhoff tank effluent.

Fig. 5.—Activated sludge unit.

The unit consists of two wooden aeration tanks, a wooden settling tank equipped with sludge removal equipment (Fig. 5), a blower for supplying air, two return sludge pumps, and metering and sampling equipment.

Each aeration tank is 12 ft. wide and 12 ft. deep, inside and 24 ft. long overall. The tanks are made of 3 in. fir and are thoroughly rodded with transverse and longitudinal rods passing through the tank.

Air is supplied through standard 12 in. square diffuser plates. There are 18 plates per tank and they are set in 6-plate concrete containers. The plates are located along the side of the tank. Each plate container is separately valved.

Timber deflectors at the top of the walls and timber corner fillets at the tank bottom are provided.

The depth of liquid over the diffuser plates is 10 ft., giving a free

board of 18 inches. The depth may be reduced to 8 ft. over the diffuser plates, if desired.

The tanks are operated in series. The sewage is passed from the first to second tank through two 10 in. steel pipes. All inlets and outlets are baffled to minimize short circuiting. The effluent is drawn from the second tank over an effluent weir 2 ft. long.

The settling tank is 24 ft. outside diameter (22 ft. 6½ in. inside). The water depth at the side of the tank is 10 ft. and the bottom slopes 1 in. per foot towards the center. An effluent weir and trough is located around the inside periphery of the tank. The trough is 8 in. wide and 10 in. deep.

Influent is admitted to the tank through an 8 in. line which enters the tank at the bottom and rises at the center. A flanged cross at the upper end of the riser supports a 4½ in. shaft on which turns a 50.67-in. pitch diameter spur gear. The upper end of the shaft is tied in to steel framing across the top of the tank. A 36 in. diameter spiral riveted steel pipe 5 ft. 8 in. long hangs from the gear.

Hanging from the lower end of the pipe is a light steel framework on which are mounted plows for sweeping the bottom of the tank. Thus the 36 in. pipe acts both as a shaft and as an inlet well. The large spur gear is driven by a ½-horse power motor through a spur pinion, bevel gear and pinion, and two speed reducers at a speed of 1 revolution in 10 minutes. This gives a linear speed of 7.4 ft. per min. at the periphery of the tank.

Air is supplied by a size 4 Nash blower. The unit is capable of furnishing more air than is required and excess air is wasted to the atmosphere.

Two return sludge pumps are provided. Air, sewage and return sludge are metered by means of venturi tubes equipped with manometers and suitable scales. Scales for sewage and sludge are graduated in gallons per minute and the scales for air are graduated in cubic feet per minute.

The wooden tanks were furnished and erected under contract. The rest of the work was done by Sanitary District forces. Pump, motors, venturi, tubes, speed reducers and the blower were taken from stock, as were most of the pipe and fittings.

The following table shows the detention periods and settling rates possible under various conditions.

Flow, G.P.M.	No. Tanks	Depth Over Plates, Ft.	Aeration Period, Hours	Settling Rate, Gals. per Sq. Ft. per Day
290	2	10	2.0	1160
290	1	10	1.0	1160
390	2	10	1.5	1550
230	2	8	2.0	920
230	1	8	1.0	920
310	2	8	1.5	1240

The unit was placed in service December 27, 1937, with an aeration period of 2.0 hours. In 15 days of operation the suspended solids concentration in the aeration mixture had increased to 2000 p.p.m.

Acknowledgment

The high rate trickling filter was built under the direction of Philip Harrington, who was Chief Engineer of the Sanitary District at that time. The other units were built under the direction of William H. Trinkaus, Jr., Chief Engineer. The Division of Maintenance and Operation, under L. M. Johnson, Engineer of Maintenance and Operation, has provided operating personnel. Mr. A. H. Goodman, Engineer of Plant Operation, is in charge of the West Side Sewage Treatment Works. Langdon Pearse, Sanitary Engineer, Dr. F. W. Mohlman, Director of Laboratories, and L. C. Whittemore, Engineer of Design, have supervised the general operating procedure of the units.

The Public Works Administration has been represented by Joshua D'Esposito, as Resident Projects Engineer. The members of the P.W.A. Board of Review are Messrs. D. W. Mead, C. W. Kutz and W. B. Storey.

Plant Operation

BETTER SEWAGE WORKS *

By George B. Gascoigne

Gascoigne and Associates, Cleveland and New York

Your Program Committee (in selecting me to address you today), left the question of a subject in my hands. Also, it is probably true that these meetings should be devoted to improving our technical knowledge in the Art of Sewage Disposal, but I am not inclined to talk with you about newer developments, trends in practices, or past accomplishments and like subjects. What I wish to do is to discuss the "human equation" which enters into making sewage works successful or better, and, in doing so, to present some of the logical and reasonable responsibilities of the various interests involved and to stress the mutual cooperation that must exist.

Interests Involved

How many of you have ever concentrated long enough to determine in your own mind just why, in certain instances, sewage works may not be suitably located; why they may not be of the proper type, of sufficient capacity, properly designed and operated? If you have you will have realized how difficult it has been to obtain sewage works even as good as they are today, especially when so many interests seem to have so much information which may or may not be of value.

In practically all present day sewage projects we have the interests of the federal, state and municipal officials, engineers, operators, contractors, equipment and material manufacturers, promoters and others. Each of these interests is trying to accomplish something worthwhile in his field, to make an honest living and to receive due and proper recognition. A handicap is created merely by having such a large number of interests all closely related to the problem, and the overlapping of the required and assumed functions of these various interests magnifies the handicap to major proportions.

Squarely facing this condition, I sometimes marvel at how fortunate we are to have as many successful works as we do. No one is to be blamed for this state of affairs; rather let us say that overlapping of functions is something that just grew. For the future, however, we must agree that this overlapping must be cut back until the functions of the various interests are properly correlated within reasonable bounds and accept the basic fact that, for successful work, responsibility for this correlation must rest upon some particular individual.

* Presented at the Tenth Annual Meeting of the New York State Sewage Works Association, New York City, January 21, 1938.

Federal Officials

During the past few years our government, through the Federal Emergency Administration of Public Works, has particularly interested itself in the construction of sanitary facilities that will relieve pollution of our streams and will supply suitable water for domestic and like purposes. The efforts of this agency had been mainly in the direction of assisting in the financing of the projects and assuring that full value is received for the money spent. This undertaking has been worthwhile and has enabled many units of our population to obtain sanitary facilities that otherwise they could not have had. However, the volume of work has been so large and its inception and prosecution has been so speeded that the supply of properly qualified and experienced talent has been grossly inadequate. Obviously, then, if value were to be received for the money spent, it was necessary for the government to carry its review and supervision further into the design field than would ordinarily be required. It is, of course, needless to say that in the case of federal agencies any functional overlapping with other interests will recede with the retarding of governmental activities in the sanitary field.

State Officials

The various states have health departments, water commissions and like agencies which were created by statute for the primary purpose of controlling the pollution of our streams and assuring safe and adequate water supplies. It follows that these sanitary improvements must meet the standards of these agencies and have their approval.

If I interpret these statutes correctly, they prescribe that the state authorities should establish the standards that must be met and generally there are laws adequate to confer upon these authorities the powers necessary to assure continued conformity with prescribed standards. I doubt if these statutes prescribe that state agencies should require a municipality to locate a sewage works at any certain site; to construct a particular type of sewage works; and to use revolving distributors instead of spray nozzles. However, circumstances beyond their control have drawn them from their prescribed field of activity to review proposed works from a detailed design standpoint and to pass upon promotional methods of treatment yet in their experimental stage. Probably this condition is especially noticeable in the smaller civil divisions, where municipal officials cannot be made to see the wisdom of employing competent engineering talent. Common jurisdiction, as distinguished from co-operation, works not to the advantage but to the disadvantage of all the interests involved.

Another difficulty hampering the efforts of state officials and all other interests is the policy of sanctioning operators whose qualifications are often measurable only in terms of political equations. Many hours of effort are spent upon men of this caliber—useless hours, because sooner or later this type of operator disappears from the picture

and we are back where we started. It is clear, I believe, that this comment bears no relation to the outstanding work state officials are performing to improve the standards of the operating profession as a whole.

In view of the many handicaps confronting them, just how can state officials be helpful in making better sewage works? All of us must do all that we can to relieve our state authorities of burdens that are not truly theirs and thereby enable them to supplement the splendid work they do in the missionary and operation fields.

Municipal Officials

Municipal officials—legislative, executive and administrative—are usually and properly concerned with objectives to be obtained and the means of obtaining them in an efficient and economic manner, together with the entire financing of the project. Happily, we find many municipal officials very much interested in these major aspects of the problem, but all too often we find them considering, passing upon, and deciding technical questions that are entirely outside their training and experience. It has been amply demonstrated that where municipal authorities confine their activities to the major aspects of the problem and delegate the technical aspects to qualified talent, the best solution of this problem results.

In what manner can municipal officials contribute to the making of better sewage works? Is it not by setting up adequate finances not only for the construction of the works but also for their operation and maintenance? Is it not by co-operating with state authorities; and is it not by securing the best available services for design, construction and operation of the improvements involved?

Engineer

I have already pointed out that in order to obtain better sewage works the functions of the various agencies must be properly correlated. If this be granted, it follows that there must be a single coordinating authority. Properly, this is the field of the engineer. His is the task of translating the general into the particular, of assigning to each a part, and the balancing as between all.

This is not glorification of the engineer—it is his job—and the point to be made is that the role of engineer carries responsibilities that are not always met. Probably few engineers are equipped to assume such responsibilities, even in their own field. However, for proper effectiveness, any deficiency should be offset by compensating qualities, prominent among which I would place a strong sense of balance and the possession of those human qualities which will make it possible to reconcile divergent views and bring the several working forces to a proper result.

One other point among many is engineering operation. Until the engineer of design has crawled into some 18-inch space to make a re-

pair or has wrenched his back in opening a large valve, he is poorly equipped to understand some of the operator's problems. It is all very well to draw pretty pictures and invent trick gadgets and try to advise an operator who knows more about his job than you do, but let us always view the structures we design through the eyes of the man who has to live with them.

Engineers are prone to consider operators as some kind of "quick-change artists" or condemn them as having a "change complex." Many operators do have a change complex, but why? For one thing, think how often a man is literally dumped into a new plant to operate it, without any fore-knowledge of how the engineer intended the plant and its component parts to be operated. If the operator tries to operate the plant as he thinks it should be operated and it does not work, what shall he do? Change it, of course, and criticize the engineer for giving him something unworkable. How many engineers have sat down and written out the story of operation as it was intended to be? Perhaps such a story would be of assistance to an operator in breaking in a new plant with a green crew.

How best can the engineer contribute to better sewage works? He can be the co-ordinator; in fact, he can be progressive and he can co-operate to the fullest extent with all of the other interests involved.

Equipment Manufacturers

If you stop to consider, about the only essential difference between the equipment representative and public officials, engineers and operators is that he usually carries a portfolio. This man has something to sell, just as the rest of us have, but his label is a little more obvious.

I am sympathetic towards these men and the firms they represent because they are the ones who have made a lot of mistakes and their mistakes are measured in dollars and cents. Also, they know how to design pumps, chains, pyrometers, valves, etc. Fortunately, most of us are now convinced that in purchasing equipment from a reputable manufacturer we are receiving the benefit of his experience. How much experience has he had? How much pioneering work has he done? How many mistakes has he made? How much does he know about the lubrication of his equipment? What quality of service does he give after he gets the order? And how much service if faults appear? It is in questions like these that we are fundamentally interested today.

The equipment manufacturer has learned a lot and is continuing to learn, but he still has a long way to go. It is within the province of all of us to encourage him. This does not necessarily mean seeing that he gets an order, but rather it means giving him the benefit of our experience in connection with, and as it affects, his equipment. Neither does it mean that we should make a place for one man's equipment when others would better serve. Instead, we should expect the manufacturer to say frankly that his equipment was not designed for the service required.

A number of bad practices have become prevalent in the manufacturers' field—practices that need more discouragement than mere frowning upon; practices that must be eliminated by the manufacturer himself. Some manufacturers seem to think that after the order is at hand nothing further needs to be done about it except, possibly, a shipment must be made at some vague future date. Sometimes, it seems, for a contractor to secure from such a firm certified drawings, wiring diagrams and the like, to submit to the engineer for approval, is about as simple a task as getting water out of a dry well. Naturally, this condition does not apply to all manufacturers; in fact, some of them who comply fully with such requirements are as much discouraged as others with this condition.

What, then, can the equipment manufacturers do to assist in making sewage works better? Should they not continue to pioneer and progress? Should they not give honest recommendations and stand back of them? Should they not give service and co-operation to all other interests? And should they not eliminate all back-door and poor-loser tactics in the conduct of their business? I think they will make more money if they do and if we all are helpful we will see the day when sewage plant equipment will be purchased more cheaply, it will be more substantial, it will have a longer effective life and, as a consequence, it will mean better sewage works.

Contractors

The lot of the contractor is not one to be greatly envied; in fact, it is surprising, considering the jurisdiction exercised over him by officials, engineers, inspectors and others—who should have no connection with the particular point involved—that he is not completely exhausted with petty arguments and mere quibbling by the time he has completed his work. On the other hand, do we not know contractors who bid a job too low and anticipate that their profits can be railroaded through by extras and by chiseling their sub-contractors?

Fundamentally, however, a contractor wants to do a good job. Hence, we must remember that it is to our best interest to deal with him in a very practical manner. Remember that he is entitled to a reasonable and just profit and that we should do everything we properly can to assist instead of hampering him in his operations.

Of course, all of this does not mean that the contractor should have no responsibilities in connection with the betterment of future sewage works. His is the responsibility of complying and not the subterfuge of evading and side-stepping. His is the responsibility, often dumped into someone else's lap, of co-ordinating the work of sub-contractors. His is the responsibility of turning over a finished job that will be worthy of him and all other interests.

Operators

I know and like many, probably love one whom I do not see very often, and here's to you who are trying conscientiously to do a good

job. When a new plant starts in operation it is true that the engineer and the manufacturer are relieved of some part of their responsibilities but the responsibility of the operator goes on and on. It is he who keeps the plant turning out a final product that meets, or better still, exceeds requirements and standards. It is he who keeps the bearings oiled and the wheels turning. It is he who keeps the plant shipshape, free from breakdowns and attractive in appearance.

I have stated that the engineer and the manufacturer must co-operate with the operator, but co-operation cannot be one-sided. The operator must co-operate with them. When an operator takes charge of a new plant his first duty, in line with this theme of co-operation, is to learn the whole story of the problem of design and of operation and to learn it in the line of the designer's intent and free from all prejudice. In other words, the plant represents an idea and a plan of treatment, to which, essentially at least, the operator should be bound. Then, when the plant is started, he should faithfully follow the designed operating procedure until it has proved workable or unworkable. If it proves workable in all details, all is well. If not, then he should look to the engineer for guidance, advice and corrections. He should not proceed with any corrective measures until he has consulted the engineer, for, between them, they can undoubtedly pool their experience and work out the best solution of the difficulties.

The operator should accept the fact that a perfect plant has never been built, that troubles are inevitable and that the engineer is always ready to be of assistance. The only way to achieve satisfaction in dealing with the engineer is to convey such troubles directly to him and not let them become known by the grapevine system, the use of which promotes belittlement of the engineer for one's own glorification, but which may lead to boomerang effects.

Accept the engineer's advice which comes from wide experience, and as a result should be worthwhile. Consult him regarding changes and betterments, remembering that he will be glad to evaluate your suggestions in the light of past experience, and, lastly, cultivate confidence of the engineer—it will be mutually helpful.

Perhaps the operator's co-operation with the equipment manufacturer does not warrant such stringent rules as those governing his co-operation with the engineer. However, the operator should run the equipment as it was intended to be operated; especially should he use diligence in the lubrication and maintenance of the equipment.

In connection with mechanical difficulties, he should convey his troubles preferably through the engineer to the manufacturer, as well as consult the engineer before making mechanical and other changes.

The operator has to live with his sewage plant. He learns its behavior during normal and abnormal times, sunshine and storm; and sees the plant develop characteristics unforeseen and unpredicted; so the operator, confronted with the unusual and meeting difficulties, is naturally prone to condemn the process and blame everyone.

It has been my observation that as an operator gains experience and becomes more familiar with the units of his plant and means for their control, he grows more tolerant and discovers the underlying reasons for certain designs not apparent at the outset.

That the operator can be of great assistance in improving plant design there can be no doubt. This applies, however, more to details than to basic principles. Most operators are limited in their experience to one, two or three plants, so many of the fundamentals escape their observation. Experience indicates, also, that plants designed or extended by operators are apt to be "patchy." In matters of location, spacing, access and other details which have to do with the mechanics of keeping the plant operating at its proper pace, the operator can be of great assistance. An ingenious man, on even a small plant, can do much to improve the general functioning of its treatment units by the adding of gadgets here and there. Major changes, however, should never be made until the need has been definitely established.

Why is it that just as soon as an operator is placed in charge of a new sewage works he starts changing things? I am obtaining the impression that some of our operators have, if you will permit me to so name it, a change complex. What is the reason for this complex? Apparently, changes in a new plant are often not only desirable but necessary; in fact, I have seen some of my very best ideas go wrong, so what else could the operator do but make changes if the plant is to operate successfully? Perhaps the engineers have aided the growth of this change complex by not providing the operator with all the knowledge he should have with reference to the mode of operation. Fortunately, and for the best interests of all of us, I have seen this change complex disappear as the operator becomes more experienced.

What can the operator do towards providing better sewage works? Should he not accept the plant as it is and try conscientiously to make it perform in the manner expected? Should he not accept the fact that a perfect sewage plant has never been built and that some troubles are to be expected and that he should look somewhere for assistance? Should he be on the verge of a nervous breakdown because he is unable to obtain adequate appropriations for the proper conduct of his work? And, in his behalf, should not all of the other interests involved appreciate that the operator is a trained man whose experience enables him to speak with authority?

Other Interests

There remains the research angle of the problem, the promotional aspect and probably others, all of which play important roles. May it suffice to say that in my judgment the research and promotional forces have only scratched the surface, there is so much for them to do. The line of attack might well be in the direction of accomplishing more treatment in a single device, having in mind the sanitary disposal of the product produced.

Summary

The keynote of success in producing better sewage works is mutual co-operation, burying within ourselves the selfishness which is too likely to break through the surface. A co-operative attitude towards the other interests and towards this joint responsibility must be maintained, in fact, improved, because it only takes one off-key note to make discord in place of harmony. The standards of all the interests are being raised and the engineer and the equipment manufacturer must help keep the operator's standards, whose specialized field is the newest in the group and has had the most rapid rise, on the same level as their own.

One more point, and this applies particularly to the engineer and the manufacturer. They must build up the confidence of the operator and show him that they are co-operating in a concrete manner by maintaining contact with him. They cannot accept no news as good news, for many an operator has struggled along against the most trying difficulties because he had the impression that the engineer and the manufacturer could not be bothered with his troubles.

The successful sewage works of the future will be produced by those who are farsighted enough to work in common for the good of the individual sewage plant, for the good of sewage treatment as a whole, for the good of each other. These are the men who will keep their health, who will make an honest living, and who will win the recognition rightfully due them.

UTILIZATION OF SLUDGE DIGESTION GASES AT THE CONEY ISLAND SEWAGE TREATMENT WORKS *

By Wellington Donaldson and Henry Liebman

Sanitary Engineer and Mechanical Engineer, Dept. of Public Works, New York City

A year ago, in reporting to this Association preliminary operations of the Coney Island Plant, some figures were given relative to digestion of sludge and gas utilization (*This Journal,* **9**: 243, 1937). The present paper deals with the subsequent experience with digestion of sludge and utilization of the gases of digestion.

General Features of the Coney Island Plant.—The several features of the Coney Island Plant have been previously described in detail. The plant as now laid out (Fig. 1) was designed to treat a sewage flow of 35 m.g.d., employing plain sedimentation during eight months of the year, with chemical treatment and chlorination during the recreational summer months for the better protection of bathing beaches in this area of the city. Actually the plant handles an average flow of about 18 m.g.d. during the winter months and about 22 m.g.d. during the summer months. The plant has handled, for a short period, a flow in excess of 50 m.g.d. The effluent is discharged some 8,300 feet distant into Rockaway Inlet.

Area and Population Served.—The district served at present by the Coney Island Plant comprises some 3,200 acres with an estimated winter population of 139,000. The summer population is subject to considerable speculation due to the tendency of the city's population to shift to the seashores in the summer. It is known that the resident population is materially greater during summer months, while the number of visitors to the beaches runs into high figures, variously estimated by the newspapers up to a million people, transient and resident, on pleasant summer week-ends. This great variation in load makes it difficult to consider gas production on a per capita basis, such as is customary with some other communities having a more or less fixed population. The quantity of sludge solids captured, particularly volatile solids, gives a clue to the summer loading, but here again there are complications due to increased efficiency by chemical treatment.

Character of Raw Sewage.—The sewage from the Coney Island district is essentially domestic with a minor contribution of manufacturing wastes, such as laundries. As is usual with sewage collecting systems adjacent to the seashore, there is at times a considerable admixture of salt water, which is a factor in the quantity of sewage treated and possibly a factor also in the efficiency of sedimentation. As an indication of the entrance of sea water, chloride determinations are a part of the daily laboratory routine. The chloride figures, together with the

* Presented before the New York State Sewage Works Association's Annual Meeting, New York City, Jan. 21, 1938.

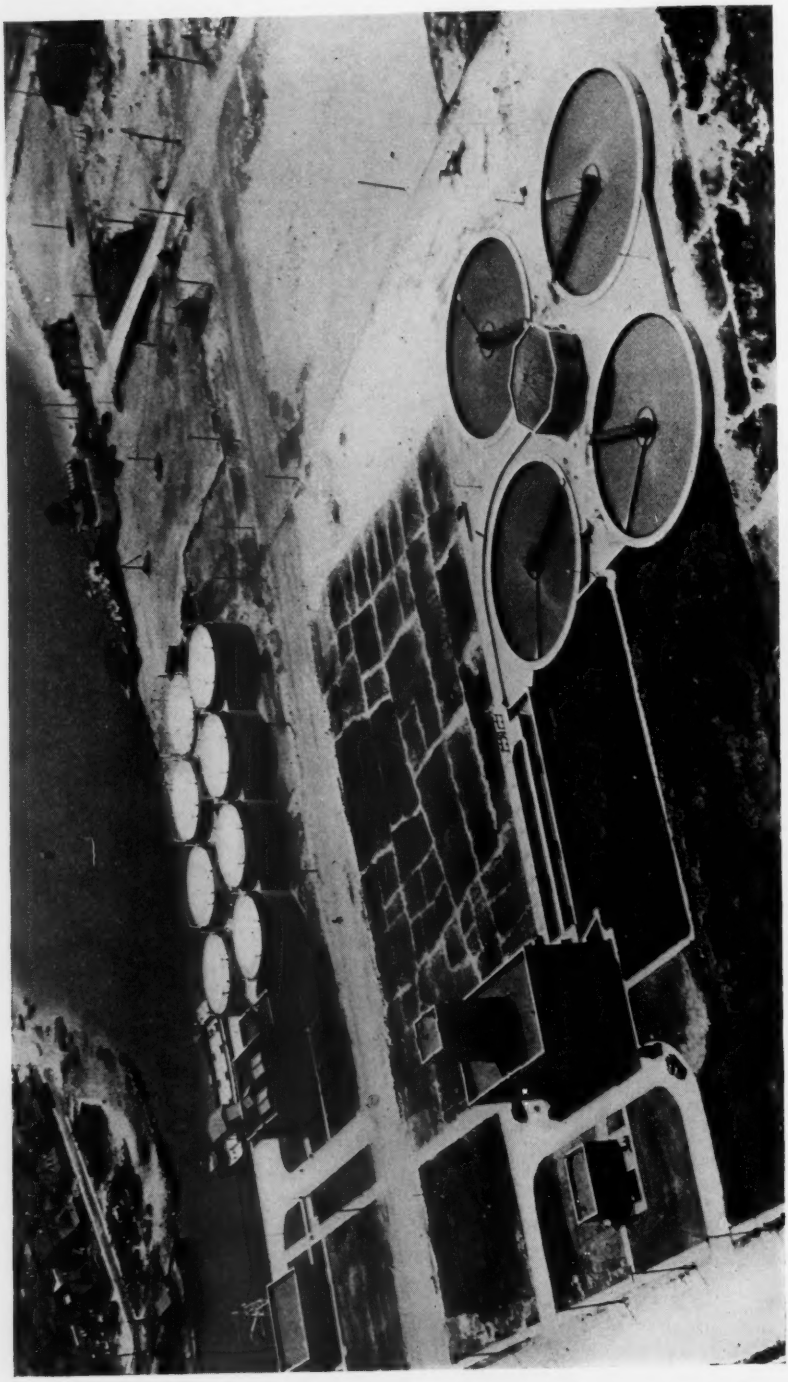

FIG. 1.—Aerial view of Coney Island Sewage Treatment Works.

appearance of live killifish in the settling tanks and increases in pumpage rates, are valid reasons for the investigation of leaks in the sewer system. Actually the chlorides in the Coney Island sewage run from a minimum of 675 p.p.m. to a maximum of 3,600 p.p.m., expressed as chlorine.

Nature of Sewage Treatment.—Except for the period January 20 to 29, 1937, inclusive, when chemical treatment was used to furnish a demonstration of full equipment in service for the benefit of visitors of this Association at its last annual meeting, the chemical feeding season for 1937 started June 15 and ended September 25. Various combinations of precipitating chemicals were used during the treatment period for the purpose of comparing efficiencies, cost, and operating difficulties. Chlorine was, of course, fed continuously in proper amounts, regardless of precipitating chemicals. Of the latter, treatment started with hydrated lime and chlorinated copperas, switched to lime and ferric sulfate (Ferrisul), then to lime and chlorinated copperas, then to lime and ferric sulfate. Subsequent to August 1st, chlorinated copperas without lime was fed.

The principal data relating to treatment are summarized in Table I.

TABLE I.—*Sewage Quality and Treatment 1937*

	Sewage Flow m.g.d.			Susp. Solids p.p.m.		B.O.D. p.p.m.		Chemical Dose, Lbs. m.g.				
	Ave.	Max.	Min.	Raw	Eff.	Raw	Eff.	No. Days	Ferrisul	Lime	Copperas	Chlorine
1	2	3	4	5	6	7	8	9	10	11	12	13
Jan.	18.4	41.0	5.0	140	73	120	85	10	—	608	193	47
Feb.	18.0	37.0	9.0	126	81	114	83	—	—	—	—	—
Mar.	16.7	43.0	6.0	140	90	133	101	—	—	—	—	—
Apr.	17.3	33.0	6.0	138	95	132	98	—	—	—	—	—
May	16.7	36.0	5.0	138	82	121	88	—	—	—	—	—
June	19.8	38.0	6.0	154	59	112	66	15	191	546	—	92
July	22.6	38.0	8.0	153	50	98	51	31	188	540	—	101
Aug.	22.3	46.0	10.0	162	45	102	46	31	—	—	309	161
Sept.	21.7	53.0	6.0	175	45	113	49	25	—	—	381	144
Oct.	20.0	52.0	7.0	144	73	89	65	3	—	—	256	71
Nov.	18.7	44.0	10.0	138	80	104	71	—	—	—	—	—
Dec.	18.4	39.0	7.0	161	81	119	85	—	—	—	—	—

In connection with the data in Table I, it should be noted that precipitating chemicals were controlled on the basis of producing an effluent turbidity of not over 50 p.p.m., this being deemed sufficient for the local conditions of effluent discharge. The chlorine dose was controlled by residual chlorine tests, whether feeding copperas, other iron salt, or chlorine alone for sterilization.

Material to Digesters.—The sludge removal mechanisms of the four Dorr center-feed settling tanks are kept in continuous operation but

sludge is pumped intermittently from these tanks to the digesters. During winter months, the sludge pumps are run from 2 to 3 minutes at each 23-minute revolution of the clarifier mechanism, during the day watch only (8 a.m. to 4 p.m.). The tank mechanisms are so staggered as to permit each of the tanks to be pumped in turn. With the increased solids captured during summer months of chemical treatment, the pump operation extends to 8 to 10 minutes each cycle and the total period of pumping to some 12 hours, so there is practically continuous addition to the digesters during a half day.

The quantity and quality of sludge pumped to digesters are given in Table II.

TABLE II.—*Average Daily Quantity and Quality of Sludge to Digestors 1937*

	Raw Sludge				Dry Pounds	
	Cu. Ft.	Sp. Gravity	% Solids	% Volatile	Total*	Volatile
1	2	3	4	5	6	7
Jan.	1,665	1.023	8.7	68.7	8,750	6,343
Feb.	2,968	1.012	8.8	70.9	16,650	11,804
Mar.	3,120	1.023	8.5	65.5	16,819	11,016
Apr.	2,642	1.025	8.2	65.2	14,020	9,141
May	2,870	1.015	9.2	61.2	16,700	10,220
June	3,770	1.012	8.3	62.3	13,680	11,833
July	5,893	1.008	8.4	60.4	27,940	18,488
Aug.	6.080	1.003	8.6	61.8	30,055	20,220
Sept.	5,750	1.012	7.9	60.8	25,660	17,059
Oct.	3,370	1.029	9.4	57.4	19,200	11,160
Nov.	2,362	1.023	9.2	57.6	14,000	8,064
Dec.	5,738	1.020	8.6	57.4	12,161	6,980
Aver. for Year..	3,854	1.017	8.7	62.4	17,970	11,861

* Correction made for chemicals added.

Grease and scum is taken from the surface of the Dorr settling tanks, about twice daily, and collected in two manholes, there allowed to stand over night for separation of the grease. The following morning the subnatant liquor is returned to the head of the plant, leaving the grease for another addition of scum. Thus at the end of the week there is left in the manholes by successive "subcantations" an accumulation of grease which is then broken up and pumped with sludge into the digesters. By this procedure the skimmings from the settling tanks are concentrated to approximately one-fifth the original volume before delivery to digesters. The concentrated grease averages some 500 cu. ft. monthly, equivalent to about 190 dry pounds daily or 9.3 dry pounds per million gallons.

Rags and other materials caught on the one-inch bar screens at the Coney Island Plant are run through a shredder and the comminuted

material is returned to the raw sewage ahead of the main pumps, thus becoming part of the sludge which settles in the settling tanks.

Digesters.—The plant has eight digestion units, each with a holding volume of 56,000 cu. ft. or combined capacity of 448,000 cu. ft. (Fig. 2). Digesters are heated by hot water coils arranged on the interior wall, the hot water being supplied either from the jackets of the gas engines, or from a separate gas-fired hot water boiler.

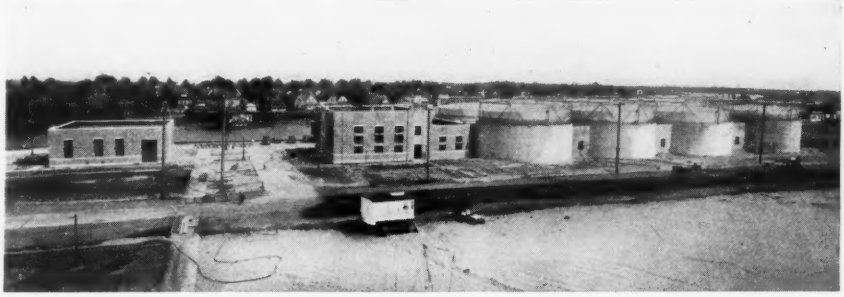

FIG. 2.—Ground view of chlorine storage building (left) and power house and digesters (right).

Each digester is equipped with a floating gas holder of the gasometer type with a capacity of 25,000 cu. ft., thus providing a total storage of 200,000 cu. ft. to make up for inequalities in the rate of gas usage.

The digester temperatures have been maintained uniformly throughout the year within the narrow range of 80° F. to 83° F.

As previously stated, pumping of the primary sludge to the digesters is usually done on the day watch. Decantation takes place the following morning or the second morning to make room for fresh sludge. During the winter months, the practice has been adopted of feeding four digester units on one day and alternating with the other four units on the next day, for the purpose of resting the digesters between doses and thereby reducing the solids in the supernatant liquor. During the height of the summer season, such a system of rotation was not permissible and the quality of supernatant liquor suffered accordingly.

Sludge is pumped to each digester receiving sludge during a two-hour period, then to other units in rotation. Measurements of sludge level in the digesters are taken before and after accession of solids, also before and after decanting. These measurements are the basis of sludge quantities summarized in Table II. Sludge digestion at Coney Island has been notably free from foaming, acid conditions or imperfectly digested material. This is attributed to the uniform temperatures maintained and to the method of feeding the units.

Digester Gas.—All of the digester gas that is utilized is registered by an orifice type Republic flow meter. The quantity of gas used by the gas engines is determined by subtracting various metered uses from the readings of the Republic meter (Table III). Besides furnishing power

for the gas engines, the digester gas is supplied to service hot water heaters in the power house and in the chemical building, to the hot water heater of the chlorine evaporators and, in case of deficiency of heat in very cold weather, to augment the hot water supply to the building radiators or to supply hot water to the coils of the digestion tanks.

There is a separate displacement meter for measurement of the gas in excess of that required by engines and other plant uses with a waste vent to the atmosphere. Actually, however, it has been found that most of the excess gas has wasted under the gasometer covers and only a small portion has been recorded by the waste meter. It is on account of this situation, therefore, that the total gas production has not been determined, although the quantity actually utilized is known with

TABLE III.—*Power Generation—Average Daily*
1937

	Gas to Engine Cu. Ft.	Per Cent CO_2	K.W.H. Generated	Ratio: Cu. Ft. per K.W.H.
1	2	3	4	5
Jan.	86,508	34.7	3,527	24.5
Feb.	88,135	34.7	3,499	25.2
Mar.	89,319	35.3	3,380	26.4
Apr.	83,299	34.9	3,430	24.3
May	89,378	35.0	3,440	26.0
June	105,715	33.8	3,829	27.6
July	123,300	30.5	4,771	25.9
Aug.	125,961	32.3	4,833	26.2
Sept.	115,235	32.4	4,424	26.1
Oct.	100,932	34.3	3,743	27.0
Nov.	92,755	34.6	3,548	26.3
Dec.	85,537	35.1	3,444	24.7
Average for 12 mos.	98,840	34.0	3,822	25.9

reasonably precision. There was no shortage of gas for all purposes enumerated during 1937. The uncertainty as to the maximum gas production and the uncertainty as to the shifting summer population has made it impossible to evaluate gas production on a per capita basis.

The carbon-dioxide content of the digester gas is shown in Table III, and the method of testing in Fig. 3.

No studies have been made of the methane content nor are calorimetric tests available. An average B.T.U. value of 650 is assumed from the carbon-dioxide figures.

Special studies made of the sulfur content of the gas, in cooperation with the Department of Water Supply, Gas and Electricity, gave a figure of 2.452 grains per 100 cu. ft.

Gas Engines.—The use of sludge gas as gas engine fuel had been successfully carried on in several installations throughout the world at the time the Coney Island Plant was designed. However, the available data on many of the important design requirements was very meager.

Since that time additional information has been published. The following experiences and engine requirements may, in small measure, add to this store of knowledge.

There are installed at the plant three generating units with provision for a fourth (Fig. 4). Each unit consists of a 300 brake-horse-

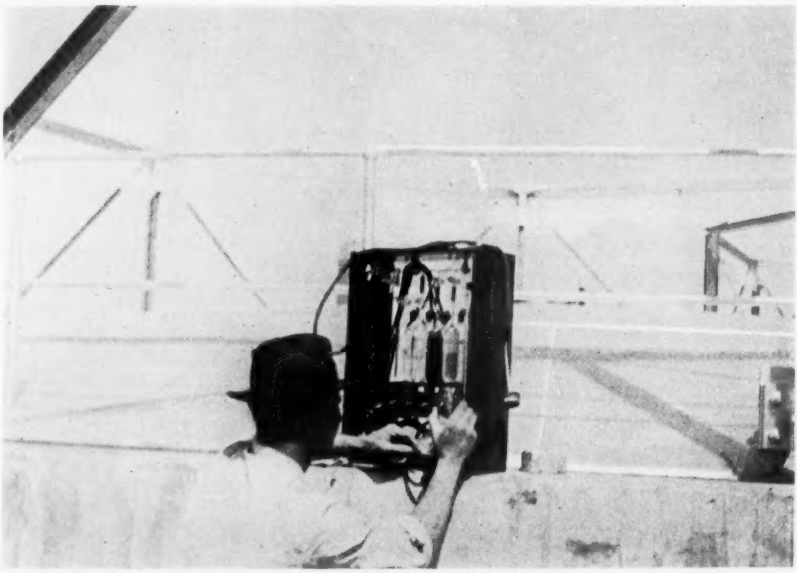

FIG. 3.—Gas analyses on individual digesters.

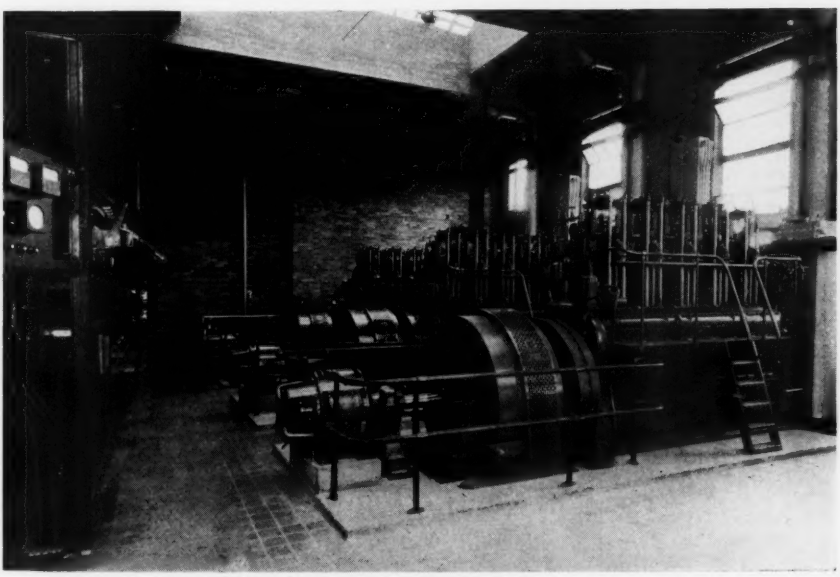

FIG. 4.—Gas engines and generators.

power Worthington gas engine with a direct-connected 200 kilowatt, Crocker-Wheeler generator, a direct connected exciter and all the necessary auxiliaries.

The engines are of the slow-speed, vertical, 5-cylinder, 4-cycle, heavy duty type. They operate at speeds between 360 and 400 r.p.m., developing 300 brake-horse-power at 69 lb. brake M.E.P. The piston speeds are less than 1,000 ft. per minute.

The construction of the engines permits conversion into Diesel units by changing heads, cylinder liners, and adding fuel pumps. The bearings and running gear were built to withstand the higher pressures encountered in Diesel operation. This feature was specified in order to obtain heavy duty, sturdy machines that would have long life.

The cylinders are provided with removable liners, which can stand three re-borings. The liners are free to expand at the lower end and are provided with glands to prevent leakage of circulating water. These glands can be repacked without disturbing the pistons or liners. The pistons were originally provided with four rings above the piston ring and one wiper ring below. Recently an additional wiper ring was installed above the piston pin. This change has made a marked improvement in oil consumption.

The cylinder heads are provided with removable inlet and exhaust valve cages. A complete set of valves and cages, ten in all, was recently purchased so that all the valves and cages could be removed at one time to be sent to the shop for re-grinding and replaced with the spare set. It has not been found necessary to grind the valves very often as the quality of sludge gas has been very good.

Each one of the engines was tested in the shop with a water brake in order to determine its gas consumption at various loads. The units were again tested in the field after the plant had been put in operation for some time and the results obtained checked very closely with the shop results and exceeded the guaranteed performance.

Generators.—The generators are of fabricated steel construction, revolving field type, provided with amortisseur windings, and are designed for gas engine operation in parallel. The units have performed very satisfactorily in service. The generators were built for 240-volt, 3-phase current, for any frequency between 54 and 60 cycles. They have a capacity of 250 k.v.a.—200 kilowatts at 0.8 power factor. They can stand an overspeed of 25 per cent without injury. With each generator there is a direct connected exciter which supplies 125 volt direct current and is rated at 10 kilowatts.

The generator units were completely shop tested and later field tested. The results showed that the performance was in excess of the guaranteed efficiency.

Since it is desirable to maintain a constant voltage, the specifications of the generators called for a unit having a voltage regulation of not over 10 per cent at unity power factor, and not over 17 per cent at 0.8 power factor. This is excellent regulation and has helped maintain constant line voltage. The units are operated at between 360 and 400 r.p.m., corresponding to 54 cycle and 60 cycle current.

By means of speed changes and resulting frequency changes, we are able to regulate the delivery of the pumps to follow the sewage flow closely, since a drop of 10 per cent in speed will cut the capacity of the centrifugal pump approximately 50 per cent at the same head.

Fuel System to Engine.—The sludge gas is brought to the engine room in a 12 in. main from the digestion tanks. Installed in the line is an orifice gas meter, previously referred to, which records both gas volume and gas pressure. For standby service, a branch connection to the gas company's main was installed. When the plant was put into operation, this gas was used for a short time. It has not been necessary to buy gas in 1937.

At each engine, there is a small receiver tank equipped with a pressure regulator to reduce the gas pressure to approximately atmospheric pressure at the mixing valve. At this point the air for combustion is mixed with the gas to the proper mixture.

The mixing valve is automatically controlled from the engine governor, which regulates fuel charge in proportion to the load. This valve can be easily adjusted to compensate for gas fuel varying in heat content. The sludge gas produced at Coney Island has a value of approximately 650 B.T.U., a high heat value. Consequently, once the valves are adjusted, there is no need for change.

The inlet of the air intake line is equipped with an air filter of the centrifugal type, which imparts a rotary motion to the air as it leaves an oil bath. The first filter installed was too large for this service, and the velocities through the filter were not sufficiently high to impart this rotary motion. They were replaced with smaller units which have performed satisfactorily.

Exhaust System.—Exhaust gases pass out through a water-cooled exhaust manifold. The temperature of the gases leaving the cylinders is about 1050° F., which is reduced to about 900° F. at the end of the exhaust manifold. Thermocouples are installed in the individual exhausts and a pyrometer is mounted on the wall at each engine.

In order to utilize the waste heat, waste heat exchangers were installed in the exhaust lines. These exchangers reduce the temperature to approximately 250° F. They are made of stainless steel throughout, and are of the floating head shell-and-tube type.

The original stainless steel composition was not suitable for the temperatures encountered in this service. After a short time, the tubes underwent an inter-granular corrosion which resulted in failure of the tubes. In addition, the temperature of the outlet gases was reduced below the dew point resulting in condensation and causing further corrosion. The exchangers were re-tubed and the tube surface reduced so that the gases now leave at about 250° F. The exchangers also act as mufflers. However, it was found inadvisable to run the exchangers dry, hence Maxim silencers are now being installed on a by-pass.

Circulating Water System.—Each generating unit has its individual circulating water pump. These pumps are designed to deliver about 100 gal. per min. against 100 ft. head.

The cooling system is operated as a closed system to avoid clogging by deposition and corrosion due to oxygen. It was found that in summer the radiation losses were not enough to sufficiently cool the circulating water, hence a considerable amount of hot water was wasted last summer. At the present time a shell-and-tube water cooler is being installed and sea water from Shellbank Creek will be used to reduce the temperature of the cooling water during the hot weather. A hot water meter measures the water passing through each engine, while indicating and recording thermometers measure temperatures. About fifty per cent of the total heat of the fuel supplied to the engines is recovered in the engine cooling water.

Lubricating System.—The engine lubricating system provides for continual straining of the oil and force-feed lubrication throughout. In addition, a separate bag type filter can be cut in to the circuit to provide for either batch or continuous filtering. Experiments have been made with a unit containing a fuller's earth cartridge and results obtained so far are favorable. A separate overhead oil supply tank installed at each engine is filled by pumping from the underground supply tank.

Engine Foundations.—The type of foundation was carefully studied before plans were made. As finally built, all three engines were anchored to a heavy concrete block ten feet deep, which rests on piles and is completely isolated from the rest of the building. The desirability of this type of construction is manifested by the complete lack of vibration when the engines are in operation.

Continuity of Service.—The gas engine generating plant at the Coney Island sewage treatment works has been operating for about fifteen months. During this period, it has developed all the power necessary to pump sewage, operate the plant, and to supply practically all heat needed for digestion and buildings. At no time has there been a power failure. Individual units have been shut down for repairs, such as re-grinding valves, replacing magnetos, spark plugs, rocker arms, etc., but no major repairs or replacements have been found necessary to date. A recent examination revealed practically no cylinder or bearing wear.

Under full load the engines developed a brake horse power hour for every 9500 B.T.U. supplied both in tests at the shop and at the plant. Table III shows the relation between the cubic feet of gas used by the engines and the kilowatt hours generated. The average value given is 25.9 cu. ft. per kilowatt hour. Taking into consideration the efficiency of the generator, this value is equivalent to 17.3 cu. ft. per B.H.P. hour.

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THE HANDLING AND FEEDING OF CHLORINE AT THE JAMAICA, N. Y., SCREENING PLANT*

By George E. Henkel

Plant Engineer

The Board of Estimate of New York City on June 14, 1937, appropriated $90,760, for the chlorination of sewage entering Jamaica Bay at five principal outlets. The Jamaica Screening Plant, dealing with an average flow of 33 million gallons daily, is one of the principal sources of sewage discharged into the bay.

During the summer season of 1937 the screened effluent of this plant was treated with chlorine in quantities up to 3920 pounds daily. Between July 17 and September 23, inclusive, a total of 90 tons of liquid chlorine were applied.

This paper deals with the handling and feeding of chlorine at the Jamaica Station only. It includes a study of the operation of pressure-reducing valves with reference to their suitability, effectiveness, and dependability in feeding chlorine.

The new storage building is 25 by 50 ft. in plan. A monorail for a three-ton chain hoist is provided, to move the ton containers of chlorine.

The building has cradles for thirty one-ton cylinders, eight of which are in the operating pit for manifolding. There are two rows of cradling, eleven on each side, on the storage floor (Fig. 1). The eight in the operating pit are divided into two banks of four each, designated *A* and *B* (Fig. 2). The pit is arranged by means of wooden cradling around the "connection" end of cylinders to form a water tight compartment; this is to facilitate quick flooding with caustic solution in case of a severe leak. The caustic solution tank, on the outside of the building is provided with a quick opening valve, also outside of the building. The tank holds 540 gallons of a 50 per cent solution. There is a 4 in. fresh water line arranged to flood the water-tight compartment. A quick opening water valve is also outside of the building.

There are large folding doors on the west side of the building to provide ample space to load or unload cylinders from an auto truck. The monorail, in the form of a loop, extends outside of building to allow for such handling. There is an exhaust fan with necessary duct lines to withdraw the cold air from around the cylinders and discharge it to the outside of the building, which may also be used to evacuate chlorine gas in case of a leak. The construction of the building, the arrangement of storage space and operating pit are in accordance with Fire Department regulations.

Each of the eight cylinders in the operating pit is connected to a separate header with a short length of flexible copper tubing and an aux-

* Presented before the Long Island Section of the New York State Sewage Works Association, Dec. 9, 1937.

iliary valve. The two groups of pipes on the wall (Fig. 3) are the headers which connect the eight cylinders to the manifolds. The two pipes in the center of the groups are duplicate gas lines to the feeding rooms, which are in the main building; the top is painted red and the lower green. These two headers run underground from the storage building to the feeding room. At the entrance to the operating room, these two headers are fitted with shut-off valves of improved design.

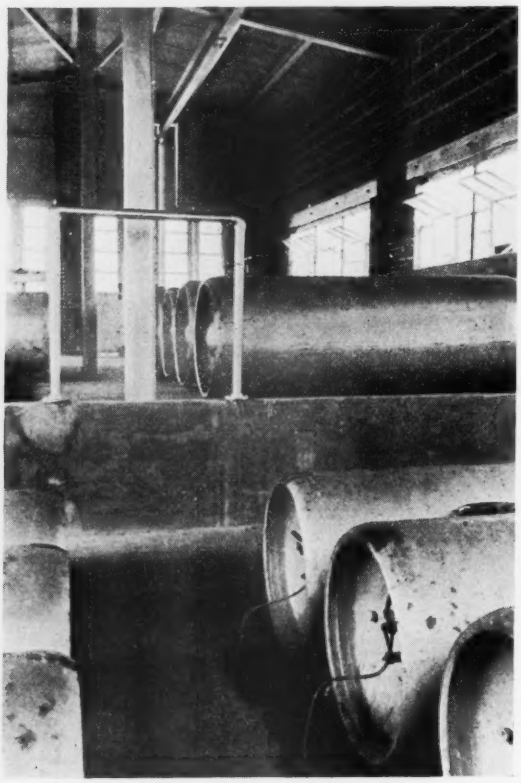

FIG. 1.—Ton chlorine containers at the Jamaica Plant.

The chlorinators feed the solution into a common solution header of rubber-lined wrought iron pipe, from which two 3 in. chlorine hose lines conduct the solution into the pump well.

The feeding installation comprises the following vacuum type chlorinators (Fig. 4):

No. 1. Pardee—200/2000 pounds per 24 hrs. adjust.
No. 2. Wallace-Tiernan—750 pounds per 24 hrs. fixed
No. 3. Wallace-Tiernan—750 pounds per 24 hrs. fixed
No. 4. Wallace-Tiernan—750 pounds per 24 hrs. fixed
No. 5. Wallace-Tiernan—100/300 pounds per 24 hrs. (adjustable)

This gives a total capacity of 4550 pounds per 24 hours.

Liquid chlorine was received in multiple unit tank cars, consisting of fifteen one-ton standard cylinders. The cylinders were removed from the cars to auto trucks, then transported to plant according to Fire Department Regulations and under its strict supervision.

FIG. 2.—Eight one-ton containers in operating pit at the Jamaica Plant.

Chlorination started July 18. A residual of between 0.2 and 0.5 p.p.m. up to August 9 was maintained at which time it was raised to between 0.5 and 1.0 parts per million. Samples were taken from the discharge side of pumps at hourly intervals and the residuals determined with a Hellige type comparator. The interval between the application of chlorine at influent of the pump well and the sampling point on the pump discharge averaged about two minutes.

Bacteriological tests of the chlorinated sewage as well as the waters of Jamaica Bay were made during the summer season. The results relating to this plant and other plants along the bay will be summarized by others.

A typical chlorine log sheet is shown in Table I. The rate of flow varied between 25.6 and 39.2 m.g.d.; the dosages varied between 62 and 142 pounds per million gallons; the residual between 0.2 and 1.0 and the rate of chlorine feed varied between 1700 pounds and 4550 pounds per 24 hours.

FIG. 3.—Manifold header and shut-off valves.

A graphical representation for the entire season, using daily averages is shown in Fig. 5. The increases in flow are due to rain storms. The peak on August 23 represents 59.5 million gallons for that day. The average dosage for the day was 95 pounds per million gallons, average residual 0.55 parts per million and 3920 pounds of chlorine.

Special Features of Chlorine Feeding

The chlorine selector valves are mounted on a panel in a weather proof cabinet on the outside wall of the chlorine storage building. Gauges are provided on the cylinder manifolds to indicate cylinder pressure, and on the reduced pressure side of pressure reducing valves to indicate reduced pressures. The pressure reducing valves are of the spring loading diaphragm type. This particular valve has a maximum capacity of 5000 pounds per 24 hours calculated at 5 pounds pressure drop. The diaphragm is made of silver, the stem and seat of platinum and body of chlorine resisting bronze casting.

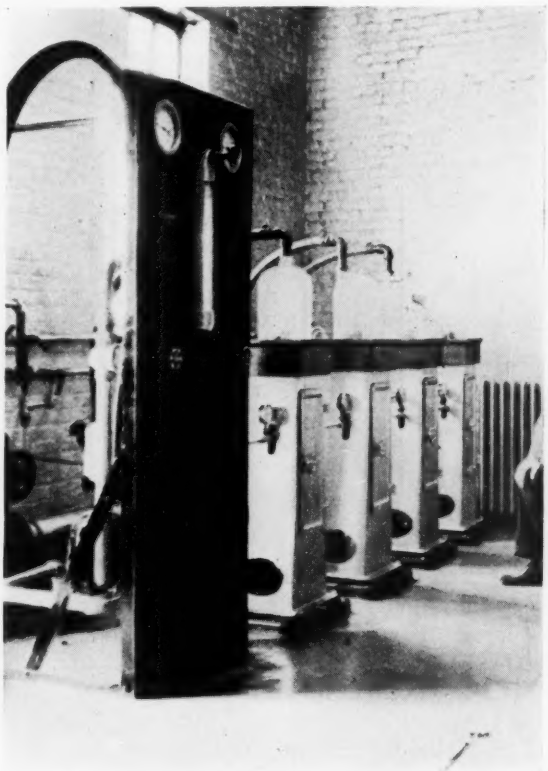

Fig. 4

If the "B" bank of cylinders is selected to deliver chlorine at 30 pounds pressure, the "A" bank is held in reserve and will deliver the gas at 20 pounds pressure, when the "B" bank pressure falls off to this value.

By virtue of this arrangement, eight cylinders can be manifolded at the same time, but four are being drawn from until the pressure falls to 20 pounds, then the four on reserve will cut in and deliver chlorine

TABLE I.—*Chlorine Log*
Station: Jamaica Screening Plant
Calendar Day: Thursday, Sept. 2, 1937

Hours	Machine Settings, Lbs./24 Hrs.						Resid. p.p.m.	Flow m.g.d.	Dose lbs./m.g.	Remarks
	1	2	3	4	5	Total				
For'd.	2000	750								
1 a.m.	2000	750				2,750	0.75	31.2	88	
2 a.m.	2000	750				2,750	.75	30.4	91	
3 a.m.	2000	2:00 Out				2,000	.50	30.4	66	
4 a.m.	2000					2,000	1.0	27.2	74	
5 a.m.	2000					2,000	.75	27.2	73	
6 a.m.	1700					1,700	.50	25.6	66	
7 a.m.	1700					1,700	.40	26.4	64	
8 a.m.	1700					1,700	.30	27.2	62	
9 a.m.	2000	9:00 In	9:00 In			2,000	.40	30.4	66	
10 a.m.	2000	750	750	10:00 In	10:00 In	3,500	.50	27.2	129	
11 a.m.	2000	750	750	750	300	4,550	.30	32.0	142	
12 N.	2000	750	750	750	300	4,550	.20	32.1	142	
1 p.m.	2000	750	750	750	300	4,550	.30	37.4	122	
2 p.m.	2000	750	750	750	300	4,550	.20	37.9	120	
3 p.m.	2000	750	750	750	300	4,550	.50	35.5	128	
4 p.m.	2000	750	750	750	300	2,275	.40	19.2	118	½ hr. Out
5 p.m.	2000	750	750	750	300	4,550	.50	38.6	118	
6 p.m.	2000	750	750	750	300	4,550	.40	34.0	126	
7 p.m.	2000	750	750	750	300	4,550	.50	35.8	127	
8 p.m.	2000	750	750	750	300	4,550	.50	34.3	132	
9 p.m.	2000	750	750	750	300	2,275	.30	17.8	128	½ hr. Out
10 p.m.	2000	750	750	750	300	4,550	.50	39.2	116	
11 p.m.	2000	750	750	10:00 Out	300	3,800	.50	31.9	119	
12 Mid.	2000	750	750		300	3,800	.75	28.1	135	
						79,750	11.70	739.0	2552	
Ave.						3,325	.49	30.8	106	

at this pressure. This will continue until the pressure reducing valve handle is raised, then the reserved bank becomes the selected and delivers the gas at 30 pounds pressure. The load on the draining bank will be transferred over to the 30-pound header until the smallest chlorinator, 300 pounds per 24 hours, is its only load. This machine is kept connected until there is no sign of chlorine gas in the bell jar; the pressure on the machine is zero; and the water level in the bell jar is above its normal height and much "air bubbling" taking place in the jar. These observations in the feeding room indicate empty cylinders. This is confirmed by inspection of the cylinders in the operating pit and it was always found that sweating had ceased and the cylinder temperature increased. The empty cylinders are then disconnected, and replaced with full ones.

At 20 pounds pressure there will be 12 pounds of chlorine gas left in the cylinders. At zero pressure there are still 5.1 pounds left in the cylinders. The Wallace and Tiernan machine operates at 2 inches of water or 1/16 th inch of mercury vacuum. These machines will with-

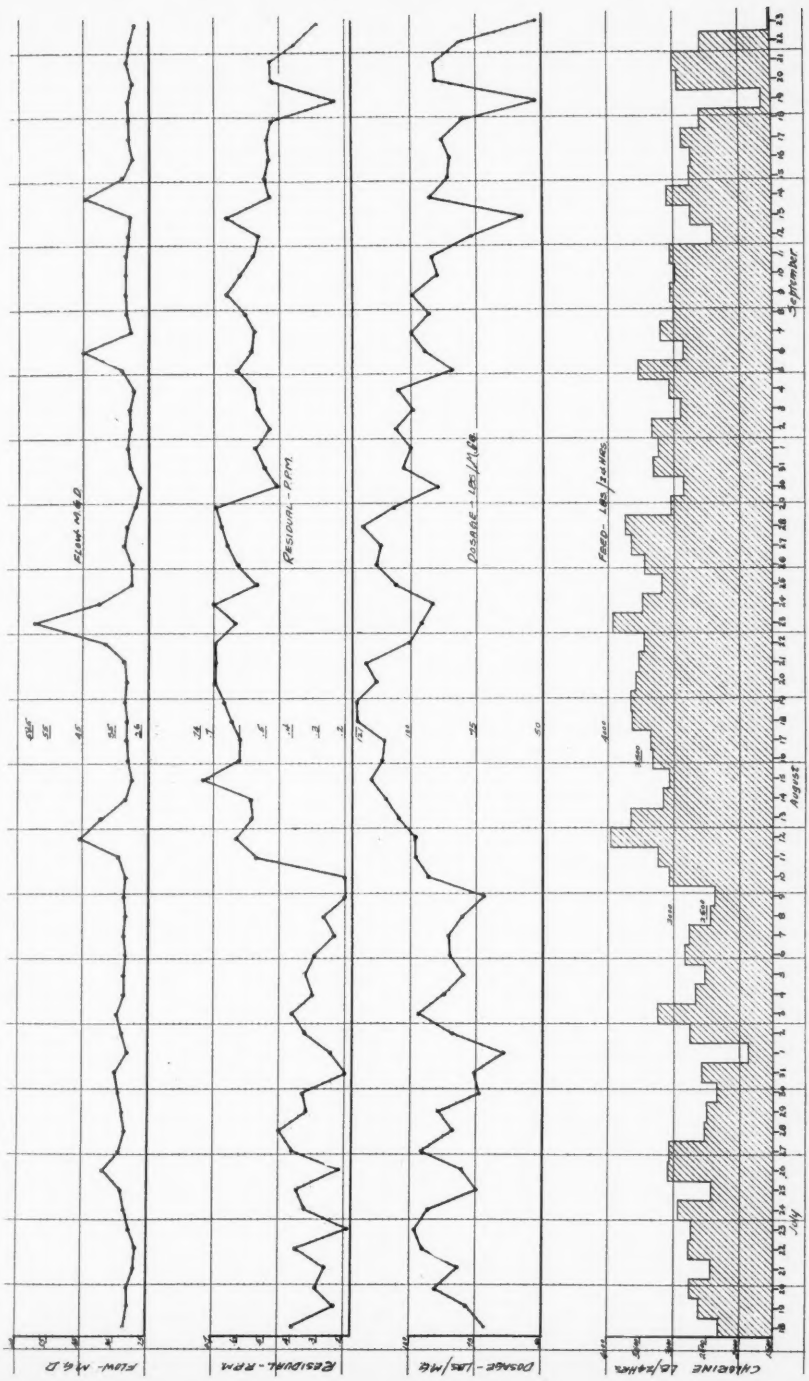

FIG. 5.—Curves on the chlorination of effluent, Jamaica screening Plant, Summer 1937.

draw a little more, but there is still about 4.6 pounds of chlorine gas left in the cylinders.

There are several distinct functions of these pressure reducing valves: (1) They hold back the chlorine in the full cylinders so as to allow the selected bank to empty. (2) They maintain a relatively uniform pressure on the chlorinators. (3) They permit no re-liquefaction to take place in the line which might otherwise be caused by low temperatures. At 20 pounds gauge pressure liquid chlorine would be present if the temperature is 8° F. and at 35 pounds gauge pressure and 27° F. liquid chlorine would be present. (4) They afford a substantial saving of chlorine as each machine delivers its definite feed and yet the cylinders are being exhausted.

During the entire season the following hourly data were collected and plotted: *Amount of chlorine feed through headers, cylinder pressures, reduced pressures, temperature of cylinders, temperature of atmosphere, number of containers connected on each bank, which pressure reducing valve "up," remarks pertaining to plant operation, and method of ventilation.* From these data and the curves, the actual operation of the pressure reducing valves can be studied as to their effective performance under variable rates of feeding.

DISCUSSION OF PAPER, "ASPECTS OF SEWAGE CHLORINATION IN 1937" *

By Linn H. Enslow and Harry A. Faber

By H. S. Hutton

Wallace and Tierman Co., Newark, N. J.

As indicated in Mr. Enslow's paper, this discussion is not a review of his paper but rather an addendum dealing particularly with the recent development of chlorinating equipment used in sewage treatment.

It was just fifteen years ago that six chlorinators, some of them with a maximum fixed capacity of 720 pounds per day and with a total capacity of 4,000 pounds, were installed in the Westerly Sewage Treatment Plant at Cleveland, Ohio. This might be classed as the first large sewage chlorination plant. It was followed the next year with an installation three times as large—eighteen chlorinators, with a total capacity of 12,600 pounds per day at the Easterly Sewage Treatment Plant in the same city.

These installations were for the sole purpose of disinfecting the effluents from these plants during the bathing season. At that time, and for a number of years after, chlorination of sewage was concerned only with disinfection. This limited the installations in sewage plants to a relatively small number and made the manufacture of standard equipment of higher capacity impractical and uneconomical.

Mr. Enslow and others have already brought to your attention the increased use of chlorine in sewage treatment for purposes other than disinfection. This has brought new problems to the equipment manufacturers. Within the past three years it has brought simultaneously installations of larger capacity and of greater number.

It is of interest to note that the Cleveland Easterly Sewage Chlorination Plant installed in 1923 still remains the largest one. It will also remain the largest for a short time longer as the City, with George B. Gascoigne, Consulting Engineer, has recently awarded a contract for the new Easterly Plant for equipment having a total capacity of 28,000 pounds to be installed later this year. The Minneapolis-St. Paul Sanitary District had previously awarded a contract for installation next year of equipment with a total capacity of 30,000 pounds per day. Several other cities are considering installations of 30,000 to 40,000 pounds of chlorine per day.

The answer to these large installations has been larger capacity chlorinators. From the original maximum of 720 pounds per day, the next step was 2,000 pounds, and now chlorinators of 6,000 pounds per day are available. Needless to say, increasing the capacity of the equipment from 720 to 6,000 pounds per day does not mean simply in-

* This Journal, **10**, 74 (Jan., 1938).

creasing the sizes of some pipes. Additional safeguards must be provided since safety, as well as accuracy and reliability, is essential.

The large quantity of chlorine required in the large plants makes it essential that every reasonable economy be provided. Several methods have been devised toward this end. First; we have step by step control with as many as six steps. Any chlorinator or series of chlorinators can be arranged by a program clock to operate at different fixed capacities during the different periods of the day and night. Second; we may have proportional control, whereby the rate of chlorine fed from the chlorinator varies in exact proportion to the flow of sewage through a Venturi tube or flume. This would be the complete answer if the chlorine demand of sewage in some installations did not vary widely. To meet this requirement, equipment is already available which, in addition to following the flows of sewage, will vary the dosage as many as a dozen times during the 24 hours. That is, if the sewage is particularly weak or strong at certain times of the day or night the chlorinators will automatically change the rate of treatment. Therefore we are treating both in respect to quantity and quality.

The final step will be equipment which feeds that amount of chlorine required to maintain a predetermined residual at all times or a certain percentage of the chlorine demand. While such equipment is already available for the chlorination of water supplies, additional research is necessary to make it practical for sewage. However, much has been done and the problem seems capable of early solution.

Sufficient water must be provided to dissolve the large quantities of chlorine, otherwise we will have merely a combination of direct feed and solution. It is customary to provide approximately 30 gallons of water per pound of chlorine. Thus, quantities of water of more than a million gallons per day, for a 30,000 pound chlorine plant, require the efficient use of water, which has brought the demand for and development of equipment which proportions the amount of water to the immediate chlorine requirement.

In some places the use of settled sewage or a more highly purified effluent is indicated, and some installations have been made. There will be some waste of chlorine by using sewage instead of water for the injector liquid. Considerable research is being done at the present time to determine this loss and the results will soon be available. The sewage liquid is usually supplied by the customary centrifugal pumps at pressures of 30 to 50 pounds.

Multiplicity of points of application of the chlorine, such as for prechlorination, at the inlet of grease removal tanks, at the outlet of grease removal tanks, to the return sludge and for disinfection, has necessitated new standards of distribution for the chlorine solution. Obviously it is desirable to have all of the chlorinators at one location for flexibility, economy of space, ease of operation and particularly for the handling of ton containers of chlorine. In most plants this is possible but requires large and expensive distribution lines—some as long as

500 feet. In the larger plants these quantities of solution require lines 3 in. or more in diameter. Within the past four years rubber-lined steel pipe, while costly, has proven most suitable for lines in general over 2 inches in diameter.

The use of iron salts for sewage treatment has also necessitated the use of high capacity chlorine apparatus. One of the most popular, chlorinated copperas, is made by combining a chlorine solution and a ferrous sulfate solution. This may be accomplished by combining the solution discharges from a chlorinator and dry chemical feeder or by pumping a copperas solution through the injector of the chlorinator.

In the so-called Scott-Darcy Process, used particularly in the Southwest, ferric chloride is made by passing the discharge of the chlorinator through a tank filled with scrap iron.

In the larger installations it is more economical and practical to purchase the chlorine in tank cars or ton containers. Equipment consisting of hoists, monorails, etc., for handling ton containers is available and used extensively.

As the field for chlorine in sewage treatment has expanded, the manufacturers have tried to meet this demand as indicated by the numerous new types of equipment made available in the past two years.

Industrial Wastes

TREATMENT OF SULFUR DYE WASTE BY THE ACTIVATED SLUDGE PROCESS

By Henry J. Miles and Ralph Porges

Special and Assistant Investigators of the Textile Foundation, Washington, D. C.

In investigating the feasibility of treating black sulfur dye waste in conjunction with domestic sewage by the activated sludge process it was decided to study, at first separately and then in combination, each of three fundamental factors controlling the process, namely: Rate of air supply, length of aeration period, and suspended solids concentration in the aeration tanks.

The first factor selected for study was the suspended solids concentration. A series of experiments were made simultaneously in four identical aeration tanks in which the amount of air supplied and the length of aeration periods were the same but the suspended solids concentration of each was held within a different range. These experiments are now being continued with different aeration periods and varying amounts of air in an effort to throw light not only upon this method of treating dye wastes but on the activated sludge process in general.

Description of Plant

The experimental plant in which these experiments were conducted is located on the property of the Proximity Print Works of Greensboro, North Carolina. It consists of a covered platform (Fig. 1) and an adjoining laboratory. On the platform are mounted the various units of the plant as shown in the general layout (Fig. 2). All tanks were made of heavy sheet iron and consisted essentially of the following:

A 240 gallon circular mixing tank (Fig. 3 foreground) equipped with a spirovortex pump mounted on a vertical axis inside the tank. The vanes of the pump suck the wastes in at the top and bottom and force them out from the center of the pump. Aeration is practically eliminated by operating at low speeds.

A 210 gallon circular primary settling tank (Fig. 3 center) equipped with continuous sludge removal equipment, consisting of four scraper arms mounted on the lower end of a vertical shaft in such a way that as the shaft revolves the settled sludge is forced into a cup at the center from which it can be drained. The incoming sewage flows downward through a flared entrance tube surrounding the vertical shaft of the scraper mechanism. The supernatant liquor is discharged into

a circular effluent channel mounted on the periphery of the tank, from which it is led to the large aeration tank.

FIG. 1.—Textile Foundation experimental plant and research laboratory at Greensboro, N. C.

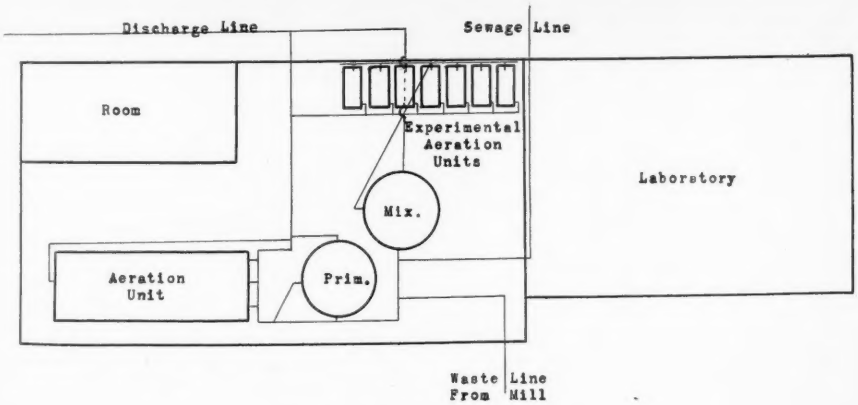

FIG. 2.—General layout of plant.

A 720 gallon rectangular aeration tank (Fig. 3 rear) equipped with a two-inch (outside diameter) porous tube aeration unit running the entire length of the tank, six inches above the bottom. Sewage is admitted through two orifices at one end of the tank and can be drained through openings in the bottom. A swinging siphon (rear end of tank, Fig. 3) is also provided for removing liquid from any desired depth.

Seven small areation tanks (Fig. 4) each of 40 gallon capacity and equipped with swinging siphon outlet pipes mounted on one side and leading to a common header. The bottom corners of the tanks are filled with tar to promote better circulation of the contents. Compressed air is supplied through short sections of four-inch diameter diffuser tubes mounted on the ends of ½ in. pipes. (Two such units are shown in Fig. 3 leaning against the outside of the mixing tank.) One unit was placed in each tank, and in the mixing tank when preaeration was desired. Air was admitted to the units from a common horizontal header mounted above the tanks, through individual orifice

FIG. 3.—Mixing, primary settling, and large aeration tank.

meters connected to water filled differential gages. Stop cocks at the outlets of the meters permitted regulation of the air supply to each tank.

Sewage was pumped from the mixing tank by a 1.5 inch centrifugal pump to these tanks through a common horizontal header just below the air line. Each outlet from the header was provided with a valve to permit the use of as many tanks as desired.

Compressed air was supplied by a Nash Hytor Compressor, the pressure being regulated by wasting the excess air through a valve in the side of the main pressure line.

Sewage was pumped to the plant from a nearby main outfall sewer of the northern section of the City of Greensboro by a one-inch cen-

trifugal pump mounted in a manhole. The sewage is of a weak domestic type but occasional large variations of the B.O.D. indicate that some industrial wastes may be present.

Sulfur dye waste from the mill was siphoned into a large storage tank from which it was drained to the plant as needed. The waste was obtained directly from the machines (jigs) used to dye the cloth and was undiluted with wash water. The dyebath consisted of the pigment or dyestuff, sodium sulfide, caustic soda, and water. The sodium sul-

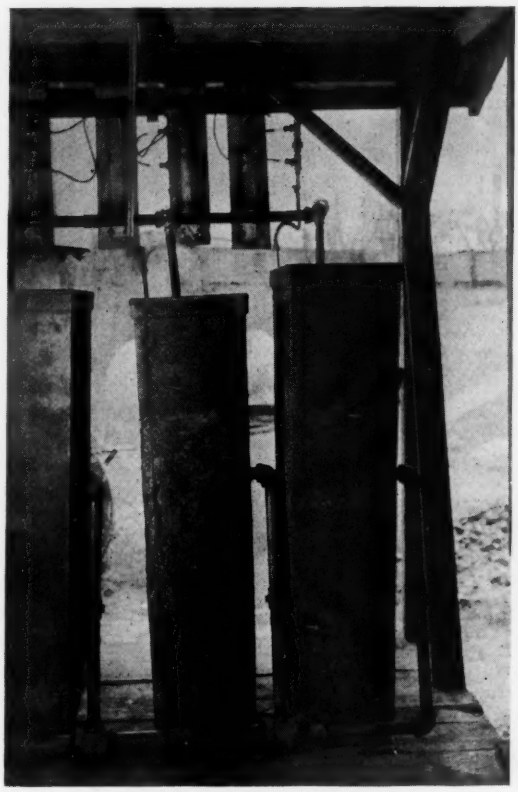

FIG. 4.—Small aeration tanks.

fide caused the normally insoluble dyestuff to dissolve in the bath. When the bath became spent a neutral salt such as sodium chloride was added to salt out more of the dye. The B.O.D. of the waste averaged about 10,000 p.p.m. and the suspended solids 1000 p.p.m. The waste had an intense black color which even in high dilutions prevented the use of most colorimetric tests and was highly alkaline.

The general piping layout is shown in Fig. 2. Sewage was pumped to the plant where it could be led directly into the mixing, primary settling, or large aeration tank. From the mixing tank it could be

pumped into any of the small aeration tanks; from the primary settling tank it could flow over the overflow weirs into the large aeration tank; and from the large aeration tank, liquid could be drawn off by a siphon from any level. All three tanks were equipped with bottom drains leading to a common drainpipe. The small aeration tanks were also equipped with siphons to permit withdrawal of the contents from any level.

Procedure

The absence of an activated sludge plant in the vicinity necessitated the building up of our own floc in the large aeration tank on a fill-and-draw basis. Sewage was pumped directly into the tank, pre-sedimentation being omitted because of the low suspended solids content of the sewage, and the sewage was aerated for nine hours using the minimum amount of air conducive to good agitation. The air was then turned off and the solids allowed to settle in the tank for two hours after which the supernatant liquor was withdrawn through the swinging siphon, and replaced with fresh sewage. This procedure was continued without interruption for about two weeks by which time sufficient floc had been formed.

Portions of the floc were distributed among four of the small aeration tanks in such quantities that, when each was diluted to 35 gallons with raw unsettled sewage from the mixing tank, the suspended solids concentrations were approximately 500, 1500, 2500, and 3500 p.p.m. respectively. The small tanks were operated on the same schedule as the large tank for about a week, floc being added or withdrawn until the solids concentrations were within 100 p.p.m. above or below the figures mentioned. By adding the sewage from the mixing tank where it had been continually mixed for the previous half-hour, uniform dosages in all the tanks were obtained.

During the next week gradually increasing amounts of dye waste were added to the mixing tank fifteen minutes before its contents were pumped into the aeration tanks. By the end of the week the concentration of the dye had reached 0.5 per cent of the volume of raw sewage added and it was maintained at this figure for 40 consecutive runs. Throughout these runs the total volume of mixture in each tank was maintained at 35 gallons. The volume of return sludge averaged very close to ⅓ of the total volume of mixture, except when some had to be removed to maintain the suspended solids concentration within the required ranges, as indicated by centrifuge tests made just before the end of each aeration period.

During the first 27 of the 40 controlled runs air was supplied at the rate of 0.32 cu. ft. per hour per gallon of aerating mixture, the minimum amount required to keep the solids in suspension. Beginning with the 28th run the rate was increased to 0.48 cu. ft. per gallon per hour and the sewage pre-aerated for one-half hour in an effort to obtain better results.

Beginning with the 41st run the concentration of the dye was periodically increased and the time of pre-aeration lengthened when considered necessary.

For purposes of comparison we used some of the original dye mixture as received by the mills from the dye manufacturers, diluting it 100 times to reduce the excessive B.O.D. and color intensity before mixing with the sewage (Group IV, Table I).

The following tests were made for purposes of control: On the raw sewage—B.O.D., suspended solids, turbidity, and pH; on the sewage dye mixture as added to the aeration tanks—B.O.D., suspended solids, turbidity, pH, color, and dissolved oxygen; on the aeration tank mixtures after fifteen minutes aeration—color; on the aeration tank mixtures just before the end of the aeration period—B.O.D., suspended solids, centrifuged solids, and settling; and on the final effluent (aeration tank supernatant liquor after ½ hour settling)—B.O.D., suspended solids, turbidity, pH, color, and dissolved oxygen.

All analyses were performed according to "Standard Methods of Water and Sewage Analysis" except where modifications were necessary to allow for the color of the dye:

B.O.D.—According to "Standard Methods" using 300 p.p.m. sodium bicarbonate dilution water. Incubation at 20° for 5 days.

Dissolved Oxygen.—Large samples were allowed to settle for ten minutes and the supernatant liquor used in the test.

Centrifuged Solids.—A 50 ml. sample was centrifuged for 5 minutes at approximately 1800 r.p.m. and the volume of sediment correlated with suspended solids determinations made on the same sample. This test was used for a rapid determination of suspended solids for plant control.

pH.—The supernatant liquor of settled or centrifuged samples was tested with the usual color standards after parallel tests with a quinhydrone electrode showed that errors caused by the color of the dye were negligible.

Color.—It was necessary to devise some standards of our own. The sulfur black waste was arbitrarily assumed to have a color of 10,000 p.p.m. and portions were diluted with tap water until colors were obtained which could be compared with the samples to be tested. As the dye has an inherent tendency to precipitate on all surfaces it was necessary to renew the standards each week.

Results

For convenience of interpretation, the significant runs were divided into four groups according to the amount of dye treated. The results obtained are shown in Table I. The figures given are arithmetical averages of the individual analyses made during every run in Group I and every fourth run in Groups II, III, and IV.

TABLE I

Group	Number of Consecutive Runs	Aeration Period in Hrs.	Volume of Air Supplied, Cu. ft. per hr. per gal.	Average Sewage Temperature, Deg. C.	Volume Sewage-dye Mixture Treated per Run, Gals.	Volume of Return Sludge as Per Cent of Total Volume	Suspended Solids, P.p.m.			B.O.D., P.p.m.		Turbidity P.p.m.		pH			Color			Volume of Solids Settled in ½ hr. as Per Cent of Total Volume	Sludge Index	Per Cent Volatile Matter in Suspended Solids in Aeration Tank at End of Aeration Period	Remarks on Sewage-dye Mixtures
							Raw Sewage	Tank Mixture after Aeration	Final Effluent	Sewage-dye Mixture after Pre-aeration	Final Effluent	Sewage-dye Mixture after Pre-aeration	Final Effluent	Sewage-dye Mixture after Pre-aeration	Aeration Tank Mixture after 15 Min. Aeration	Final Effluent	Sewage-dye Mixture after Pre-aeration	Aeration Tank Mixture after 15 Min. Aeration	Final Effluent				
I	41	9	0.32[1]	13	23	33	151	651	29	175	16	281	27	7.3	7.3	7.4	30	21	12	3.6	56.1	74.4	Runs 1–40 inc.: 0.5 per cent dye
	41	9	0.32[1]	13	23	33	151	1567	22	175	12	281	41	7.3	7.3	7.4	30	18	9	9.6	63.4	72.2	Runs 1–27: mixed 30 min.
	41	9	0.32[1]	13	23	33	151	2646	23	175	10	281	40	7.3	7.3	7.4	30	16	6	22.7	80.3	71.5	Runs 28–40: mixed and pre-
	41	9	0.32[1]	13	23	33	151	3150	23	175	10	281	39	7.3	7.3	7.4	30	14	5	26.2	83.3	70.6	aerated 30 min.
II	14	9	0.43	17	23	33	232	800	24	274	16	345	12	7.9	7.5	7.4	36	35	27	3.6	49.0	79.3	1 per cent dye mixed and pre-
	14	9	0.43	17	23	33	232	1886	17	274	11	345	14	7.9	7.3	7.3	36	30	15	10.3	67.7	75.0	aerated 1.5 hrs.
	14	9	0.43	17	23	33	232	2760	12	274	8	345	16	7.9	7.3	7.2	36	25	7	21.0	81.3	73.0	
	14	9	0.43	17	23	33	232	3628	23	274	11	345	22	7.9	7.3	7.1	36	25	7	23.5	72.9	72.0	
III	17	9	0.43	14	23	33	176	613	28	193	17	220	16	7.9	—	7.5	49	43	28	3.0	43.0	71.3	1.5 per cent dye mixed and pre-
	17	9	0.43	14	23	33	176	1694	36	193	10	220	26	7.9	—	7.4	49	41	20	10.0	56.4	70.8	aerated 1.75 hrs.
	17	9	0.43	14	23	33	176	2500	30	193	13	220	49	7.9	—	7.3	49	38	14	19.5	82.0	70.7	
	17	9	0.43	14	23	33	176	3511	34	193	15	220	44	7.9	—	7.3	49	37	12	20.0	62.8	70.3	
IV	10	9	0.43	17	23	33	223	676	17	103	5	400	17	8.3	8.3	7.6	178	88	7	4.5	62.2	80.0	0.02 per cent original dye.
	10	9	0.43	17	23	33	223	1596	11	103	20	400	10	8.3	7.7	7.4	178	32	1	12.5	80.2	70.0	Mixed 0.5 hrs. No pre-
	10	9	0.43	17	23	33	223	2440	12	103	2	400	14	8.3	7.4	6.5	178	22	2	18.5	83.0	70.0	aeration
	10	9	0.43	17	23	33	223	3523	12	103	4	400	13	8.3	7.3	6.3	178	15	1	31.0	84.8	70.0	

[1] Increased to 0.48 for last 13 runs in Group I.

In Group I, 0.5 per cent dye waste was added to the raw sewage and the mixture pre-aerated in the mixing tank for one-half hour before being added to the return sludge in the aeration tanks. Air was supplied at the rate of 0.32 cu. ft. per hour per gallon of mixture in the aeration tank—including return sludge—for the first 28 runs and increased to 0.48 cu. ft. per hour per gallon for the remaining 13 runs. The per cent reductions in B.O.D., suspended solids, turbidity, and color of the effluent as compared to the influent of the aeration tanks are shown in Fig. 5. The purification obtained, expressed in per cent, is plotted against the average suspended solids which were maintained in the respective aeration tanks during this particular group of runs.

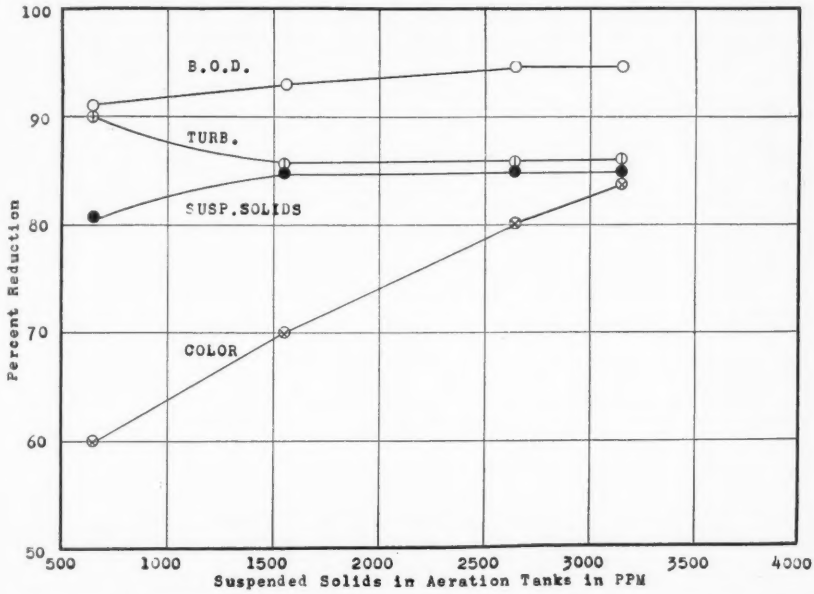

FIG. 5.—Curves showing purification obtained in four aeration tanks containing various amounts of suspended solids and treating one-half per cent dye waste.

In Group II, 1.0 per cent dye waste was added to the raw sewage and the mixture pre-aerated for 1.5 hours. Air was supplied at the rate of 0.43 cu. ft. per hour per gallon. The results are given in Table I and Fig. 6.

In Group III, 1.5 per cent dye waste was added to the raw sewage and the mixture pre-aerated for 1.75 hours. Air was supplied at the rate of 0.43 cu. ft. per hour per gallon. The results are given in Table I and Fig. 7.

In Group IV, 0.02 per cent of the original undiluted dye liquid as received by the mill from the manufacturers was mixed with the raw sewage for 0.5 hours before treatment, pre-aeration being omitted.

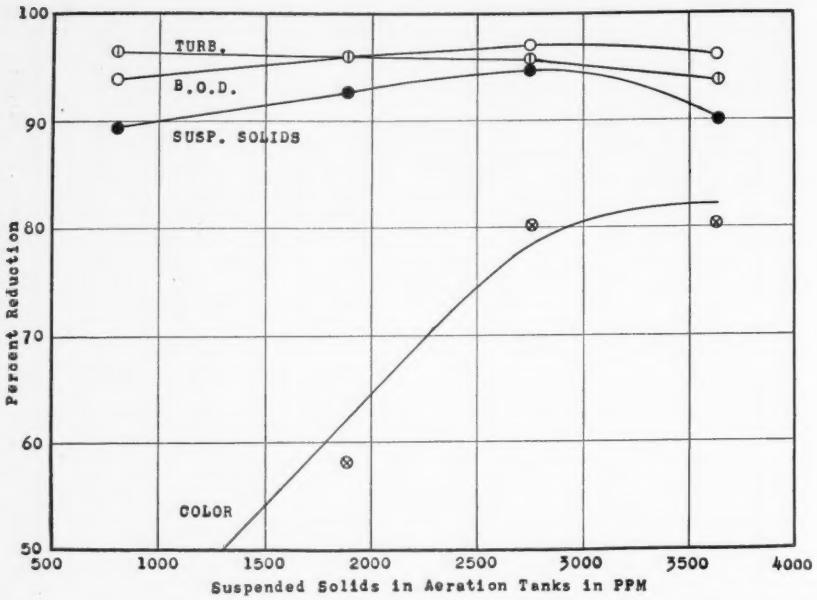

FIG. 6.—Curves showing purification obtained in four aeration tanks containing varying amounts of suspended solids and treating one per cent dye waste.

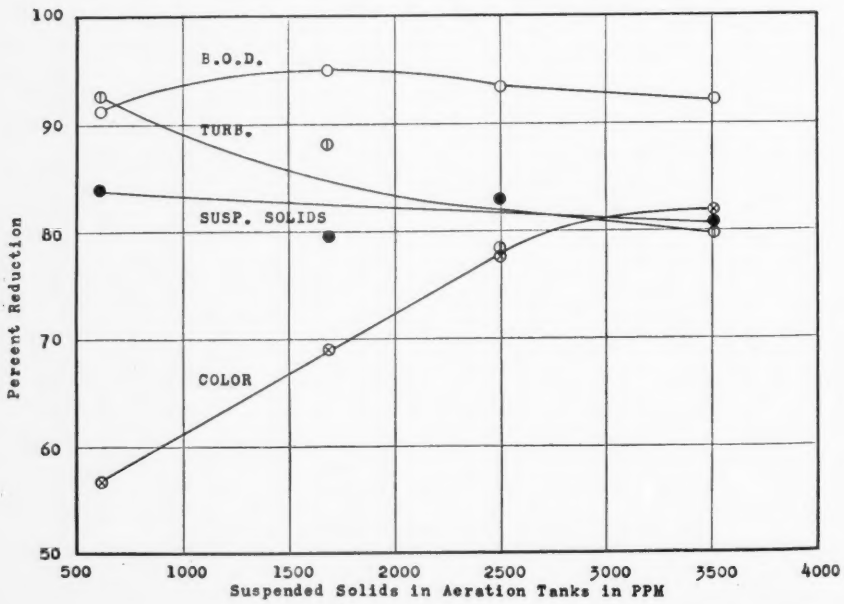

FIG. 7.—Curves showing purification obtained in four aeration tanks containing varying amounts of suspended solids and treating one and one-half per cent dye waste.

Air was supplied at the rate of 0.43 cu. ft. per hour per gallon. The results are given in Table I and Fig. 8.

In all these runs a 9-hour aeration period was used, followed by 2.5 hours of quiescent settling. Samples of effluent for analysis, however, were taken after 0.5 hours settling.

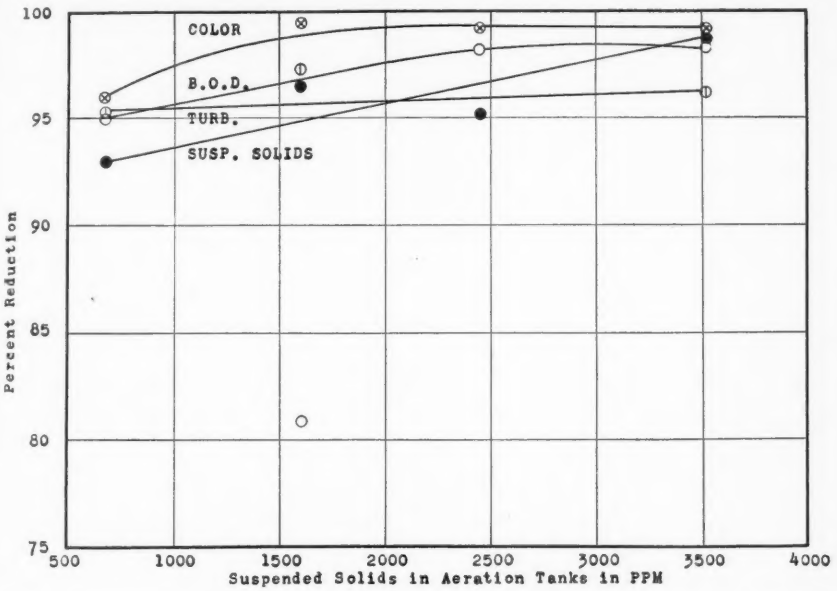

FIG. 8.—Curves showing purification obtained in four aeration tanks containing varying amounts of suspended solids and treating original dye.

Solids Balance.—Careful records were kept of the suspended solids added to the aeration tanks in the sewage-dye mixtures and removed in the supernatant liquor and sludge in an effort to determine whether or not suspended solids were lost or gained in the aeration process. Expressing the weight of suspended solids added at the beginning of each run as a percentage of the suspended solids in the tanks (dry basis) the results shown in Table II and Fig. 9. were obtained.

TABLE II

Tank No.	Average Suspended Solids in P.p.m. Maintained during Runs 1–40	Solids Added per Run as Per Cent of Solids in Tank	Solids Discharged per Run as Per Cent of Solids in Tank	Solids Destroyed per Run as Per Cent of Solids in Tank
1	651	15.30	15.30	0
2	1,567	5.50	4.92	0.58
3	2,646	3.76	2.24	1.52
4	3,150	3.15	0.47	2.68

Similar calculations, made with the data obtained during the later runs using higher concentrations of dye waste, showed no material variations from the figures given.

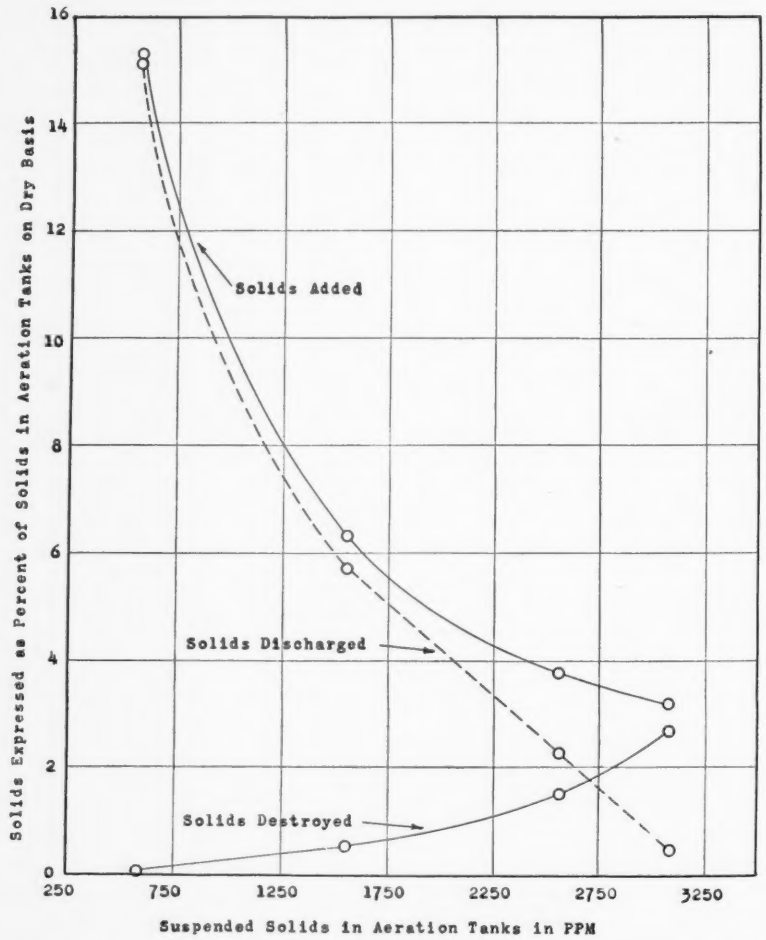

FIG. 9.—Suspended solids added, discharged, and destroyed in four aeration tanks containing different amounts of suspended solids and treating equal volumes of the same sewage-dye mixture.

B.O.D.-Suspended Solids Ratios.—The figures given in Table III are the arithmetical averages of the B.O.D.-suspended solids ratios computed from the results of analyses made on the individual runs.

Sludge Index.—As noted in Table I, the sludge index was usually highest in those aeration tanks containing the greatest concentration of suspended solids.

TABLE III

Concentration of Dye Waste in Sewage	B.O.D.—Suspended Solids Ratio of				
	Sewage-dye Mixture as Added to the Aeration Tanks	Aeration Tank Mixtures at End of Aeration Period			
		Tank			
		1	2	3	4
0.5	1.12	0.37	0.25	0.17	0.18
1.0 to 1.5	1.19	0.34	0.24	0.20	0.21

DISSCUSSION

Effect of Suspended Solids Concentration on Purification.—As criteria for measuring the purification obtained in the aeration tanks we used the reduction of color, B.O.D., suspended solids, and turbidity. The optimum suspended solids concentration for maximum purification under our specific conditions of air consumption and length of aeration periods varied, depending upon which of these indices we used as a measuring stick and it therefore seems best to discuss them separately.

Color.—The greatest color removal was obtained in the tank containing the highest suspended solids concentration. This is clearly shown in Figs. 5 to 8, inclusive, in which the color removed, expressed as a percentage of the color of the sewage-dye mixture added to the tanks, is plotted against the average suspended solids concentration maintained during the group of runs. The effluents from Tank 4 and often from Tank 3 were practically colorless.

The experiments of Dr. Heukelekian (1) and similar studies already described in this paper indicate that with a given sewage the rate of destruction of suspended solids during the aeration process increases as the concentration of suspended solids maintained in the aeration tank increases. Eventually a point is reached at which the rate of destruction equals the rate of addition of solids in the raw sewage and it is impossible to increase their concentration beyond this point. This was the condition reached in Tank 4 from which no sludge was drawn over a period of 3 months and in which the suspended solids concentration never increased more than a few hundred parts per million above the initial 3500. Therefore, with a given aeration period and rate of air supply the amount of color which can be removed will depend on the strength of sewage available.

It is interesting to note the high color removals recorded in Fig. 8. In this set of runs (Group IV, Table I) the original dye mixture as supplied to the mills was used instead of the spent wastes discharged at the end of the process. This mixture was diluted 100 times with tap water before being added to the raw sewage, the resulting overall dilution in the sewage being 0.02 per cent. The ease with which the color was removed may be due to the low sodium sulfide content of this mixture as

compared to that of the dye waste. In the dyeing process the dye pigment is deposited on the cloth but a considerable portion of the sulfide remains in the bath, hence the waste contains almost as much sulfide as the original bath. Our synthetic waste prepared by diluting the original mixture, diluted the sulfide as well as the pigment.

The pigment once separated from the solution is apparently acted upon by the organisms as no evidence could be found of an excessive accumulation of dye in any of the tanks.

That the color is removed from solution by adsorption by the floc may be indicated by the removal of as high as 50 per cent of the color during the first 15 minutes of aeration, the highest removals being in the tanks with the highest solids concentrations. The dye has a natural tendency to precipitate on any surface available.

B.O.D. and Suspended Solids.—The suspended solids concentration appears to affect the B.O.D. and suspended solids reduction very slightly, the variations being almost within the limits of accuracy of the methods of analysis. There is a slight indication that different solids concentrations are optimum for different concentrations of dye wastes.

Turbidity.—The general tendency is for the best turbidity removal to occur in those tanks having the least suspended solids.

Preliminary Treatment

Discharge of Wastes from Mills in Proportion to Sewage Flow.—As has been stated by other investigators it is most important that the wastes be discharged into the sewers in proportion to the flow of domestic sewage in the latter. Our experience with strongly alkaline wastes such as the sulfur dyes proved that sudden additions of large quantities of waste to the aeration tanks caused very high initial pH values and low pH values at the end of the process. This probably led to the difficulties experienced in previous investigations in which the floc refused to settle.

Pre-aeration.—Sulfur black dye waste has a very high B.O.D. (10,000 p.p.m.) which results in an excessive demand for oxygen at the beginning of the aeration process. To offset this demand to some extent we tried pre-aeration of the sewage-dye mixture before mixing with the return sludge. It was impossible to tell when dissolved oxygen was present except when lower concentrations of dye were used as the intense black color interfered with the standard test. Pre-aeration seems to help the process but we do not wish to make any definite statements until certain experiments now under way are completed.

Removal of Color by Mixing with Sewage.—As high as 40 per cent of the color was removed from the dye by mixing for 15 minutes with raw sewage. This does not include the reduction in color by dilution. In a municipal sewerage system, a large proportion of the color should be removed from the waste by mixing with the sewage in the sewers before reaching the plant.

Amount of Black Sulfur Dye Waste Which Can Be Treated.—The

dye waste which we treated was the undiluted waste from the dyeing jigs. We have been able to handle as high as three per cent of this waste on the basis of raw sewage added daily, and there are no indications that we have reached the upper limit. If this waste were led into equalizing tanks before being discharged into the sewers it would be diluted by the rinse water used in the process approximately 130 times, or, in other words, the dye waste is 0.8 per cent of the total volume of waste discharged from the jigs. Assuming that the first rinse waters are almost as concentrated as the spent dye bath, the resulting strength of the mixture is still well within the concentrations we have handled.

Summary

The treatment of sulfur dye waste mixed with domestic sewage was studied on a semi-plant scale by the batch process over a period of three months.

Four identical aeration tanks containing approximately 500, 1500, 2500, and 3500 p.p.m. suspended solids were operated in parallel, using 9-hour aeration periods and 3.86 cu. ft. of air per gallon of aerating mixture.

The B.O.D. and suspended solids reductions were practically the same in all the tanks. The color removal was greatest in the tank containing the most suspended solids while the best turbidity reduction was obtained in the tank containing the least suspended solids. With proper control it was possible to obtain a sparkling clear effluent having a B.O.D. of less than 15 p.p.m.

No evidence could be found of an excessive accumulation of dye in any of the tanks.

As high as three per cent of the concentrated waste was successfully treated, which is considerably above the concentration which will be obtained in the local municipal sewage if the large volume of rinse water used in the dyeing process is included.

It is most important that the dye wastes and rinse waters be mixed in equalizing tanks before discharging into the city sewers in proportion to the sewage flow.

The length of aeration period and rate of air consumption used in these experiments were selected mainly for convenience in our experimental plant and should not be considered the minimum values in the treatment of the sulfur dye wastes.

Acknowledgment

The authors wish to express their sincere appreciation to Dr. H. G. Baity of the University of North Carolina and Dr. Willem Rudolfs of the New Jersey Agricultural Experiment Station for their very helpful criticism and advice and to Mr. C. W. Smedberg, City Engineer of Greensboro, N. C., and the Cone Textile Mills for their cooperation in this work.

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1. H. Heukelekian, *This Journal*, **7**, 405–416 (1935).

Operators' Reports and Suggestions

W. D. Hatfield

219 Linden Place, Decatur, Ill.

QUALIFICATIONS PRESCRIBED FOR SEWAGE TREATMENT PLANT OPERATORS IN NEW YORK STATE *

By Anselmo F. Dappert

Principal Sanitary Engineer, New York State Department of Health, Albany, N. Y.

Under the provisions of Chapter 628, Laws of 1937, the Public Health Council of the State of New York was authorized to prescribe the qualifications of dairy and milk inspectors and operators of public water and sewage treatment plants. This amendment to the Public Health Law contained certain exemptions as applying to existing operators and to operators who are not paid from public funds, which have been incorporated in the amendment to the State Sanitary Code presented herewith.

For a considerable period of time the Public Health Law has provided authority to the Public Health Council to prescribe the qualifications of local health officers, public health nurses and laboratory personnel and such qualifications have been established by the regulations of Chapter XI of the State Sanitary Code. Under the recently amended law the authority of the Public Health Council in this respect has been extended similarly to cover dairy and milk inspectors and the operators of public water and sewage treatment plants. Thus sewage works operators as a group have been definitely and officially recognized as public health personnel.

After several months consideration, the Public Health Council has amended Chapter XI of the State Sanitary Code by the addition of Section F which prescribes the qualifications of sewage treatment plant operators. This section follows the general pattern of the section applying to local health officers and contains comparable regulations.

The main thesis of the regulations may be simply stated. For new appointments, they require municipalities to select operators who have certain definite qualifications based upon the size and character of treatment plants to be operated. They do not apply to New York City operators nor to operators of private treatment plants. They do not apply to operators who have been appointed to their positions prior to October 1, 1937, nor to operators appointed from Civil Service lists established prior to this date. They provide for a waiver of the requirements under special and meritorious circumstances and a degree

* Presented at the Fall Meeting of the New York State Sewage Works Association, Elmira, Oct. 16, 1937.

of flexibility which is essential to any reasonable program of protecting competent operators and elevating the general standards of sewage works operating personnel. They apply not only to the chief operators but also to their subordinates if they are in responsible charge of the plant for any period of time or of any essential part of the plant.

Although the regulations do not apply generally to any of the existing operators, it is to be noted that this exemption does not give any blanket recognition to existing operators as qualified operators. Most of the operators in the State will undoubtedly want to become so recognized and the regulations accordingly provide that any operator may submit his qualifications to the Public Health Council for an opinion as to whether or not they meet the requirements.

It is to be noted that the regulations do not provide for the licensing of operators. They simply provide that a new operator shall have certain prescribed qualifications in one of three grades defined by the type of plant he is to operate. Operators who submit their qualifications to the Public Health Council for review can expect, therefore, to receive only an opinion as to whether or not they meet the requirements. However, it is possible that in time some form of certificate may be issued. However, in their general effect it is believed that the regulations will accomplish the same purposes and objectives as would be secured through some form of licensing law.

As applying to existing operators the requirements are reasonable. They are not required to have any particular qualifications but if they wish recognition as qualified operators they must conform to the requirements. The regulations do not penalize an operator for lack of academic training provided he has a satisfactory experience record and in cases where some further education is required the regulations establish the base for this by requiring completion of special courses of instruction approved by the Public Health Council as qualifying for one of the three grades. Plans are now under way for the establishment of two weeks short courses in one or two of the universities to meet the particular needs in this respect.

But applying to future operators the requirements, although reasonable, are quite high. Their general effect will be to cause the selection of operators of Grade I plants from among engineering graduates and operators of Grade II plants from among the group of Grade III operators who by experience and study have been able to achieve the qualifications prescribed for Grade II. By the very reason of this, therefore, existing competent operators are given a great deal of protection in their positions. For in the case of a displacement, the appointing authority is immediately confronted with the necessity of selecting an operator who has the prescribed qualifications. At the present time there are very few persons, not now employed in a plant, who can meet both the educational and experience requirements for Grades I and II.

The recently enacted regulations comprising a part of the State Sanitary Code, Chapter XI, are as follows:

Section F—Operators of Public Sewage Treatment Plants

Regulation 45. Definition.—The term "operator" as used in this section shall mean any individual, who is paid from public funds and who is employed or appointed by any county, city, village, town, or district, or by any state department, as the person in charge of the operation of any sewage treatment plant or essential part thereof.

Regulation 46. Qualifications Required.—No person shall be appointed hereafter as operator unless he shall possess at the time of appointment the qualifications hereinafter prescribed for such position, except that this requirement shall not apply to operators employed prior to October 1, 1937, nor to operators appointed to positions from civil service lists established prior to October 1, 1937.

Regulation 47. Preliminary Qualifications.—An operator shall be physically capable of performing his duties, able to read, write, and make simple arithmetical computations and shall produce evidence acceptable to the appointing authority as to his character and his ability to maintain and operate properly all equipment entrusted to his care.

Regulation 48. Grades Established.—There are hereby established qualifications for operators in three grades, to be known as Grade I, Grade II, and Grade III.

Grade I. The following operators shall have the qualifications prescribed for Grade I:

(1) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of more than 40,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary; or,

(2) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of from 20,000 to 40,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of the process of separate sludge digestion, chemical precipitation, incineration of sludge, activated sludge, or biological oxidation; or,

(3) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of from 10,000 to 20,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of the activated sludge process.

Grade II. The following operators shall have the qualifications prescribed for Grade II:

(1) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of from 20,000 to 40,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of any process except separate sludge digestion, chemical precipitation, incineration of sludge, activated sludge, or biological oxidation; or,

(2) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of from 10,000 to 20,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of any process except activated sludge; or,

(3) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of from 5,000 to 10,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of the process of separate sludge digestion, chemical precipitation, incineration of sludge, activated sludge, or biological oxidation; or,

(4) Operators responsible for or in charge of any sewage treatment plant to which the sewage of less than 5,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of the process of gas collection, chemical precipitation, or activated sludge; or,

(5) Operators acting under general supervision in plants required to be under the charge of Grade I operators.

Grade III. The following operators shall have the qualifications prescribed for Grade III:

(1) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of from 5,000 to 10,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of any process, except separate sludge digestion, chemical precipitation, incineration of sludge, activated sludge, or biological oxidation; or,

(2) Operators responsible for or in charge of the operation of any sewage treatment plant to which the sewage of less than 5,000 persons, or the population equivalent, as determined by the bio-chemical oxygen demand, is tributary and in which plant use is made of any process, except gas collection, chemical precipitation, or activated sludge; or,

(3) Operators acting under general supervision in plants required to be under the charge of Grade II operators.

Nothing herein shall be construed to prevent the employment or appointment of an operator in a grade lower than that for which he is qualified.

Regulation 49. Qualifications, Grade I.—The qualifications for operators in Grade I shall be practical experience and special training and education in sewage treatment, consisting of:

(*a*) Graduation from a university or school of recognized standing with a degree in public health, sanitary, chemical, or civil engineering, provided that graduates in chemical or civil engineering shall have completed acceptable courses in sanitation; and, provided that all shall have had not less than one year of satisfactory experience in a sewage treatment plant; or,

(*b*) Completion of a course of instruction in sewage treatment approved by the public health council as qualifying for this grade, provided that such persons shall have had not less than three years of satisfactory experience in a sewage treatment plant; or,

(*c*) Any combination of education, training, and experience which in the opinion of the public health council is the equivalent of either of the above qualifications.

Regulation 50. Qualifications, Grade II.—The qualifications for operators in Grade II shall be practical experience and special training and education in sewage treatment, consisting of:

(*a*) Graduation from a high school and completion of a course of instruction in sewage treatment approved by the public health council as qualifying for this grade, provided that such persons shall have had not less than one year of satisfactory experience in a sewage treatment plant; or,

(*b*) Completion of a course of instruction in sewage treatment approved by the public health council as qualifying for this grade, provided that such persons shall have had not less than two years of satisfactory experience in a sewage treatment plant; or,

(*c*) Any combination of education, training, and experience which in the opinion of the public health council is the equivalent of either of the above qualifications.

Regulation 51. Qualifications, Grade III.—The qualifications for operators in Grade III shall be practical experience and/or special training and education in sewage treatment, consisting of:

(*a*) Not less than one year of satisfactory experience in a sewage treatment plant; or,

(*b*) Completion of a course of instruction in sewage treatment approved by the public health council as qualifying for this grade, provided that such persons shall have had not less than three months of satisfactory experience in a sewage treatment plant; or,

(*c*) Any combination of education, training, and experience which in the opinion of the public health council is the equivalent of either of the above qualifications.

Regulation 52. Submission of Evidence of Qualifications.—Any person may submit evidence of his qualifications or any appointing authority may submit evidence of the qualifications of any person, to the public health council for opinion as to whether or not such person meets the qualifications for operators in a specified grade.

Regulation 53. Authority to Waive Requirements or to Require Examinations.—The public health council may, under special circumstances specified by the local appointing authority or by the proposed operator, waive the requirements in any grade as to any proposed appointment, such waiver to be valid for such period as may be specified by the public health council but not for a period longer than the term of the proposed appointment. The public health council may require any person, whose qualifications it is called upon to consider, to take such written, oral, or practical examination as it may direct.

Regulation 54. When to Take Effect.—Every regulation in this section shall take effect on October 1, 1937.

OPERATORS' GADGETS

These gadgets were not entered in any contest but were submitted to the editor without special invitation. Will not more of you do the same thing?

W. D. HATFIELD

SEWAGE FLOW VELOCITY METER

BY ISADORE J. DUBOIS

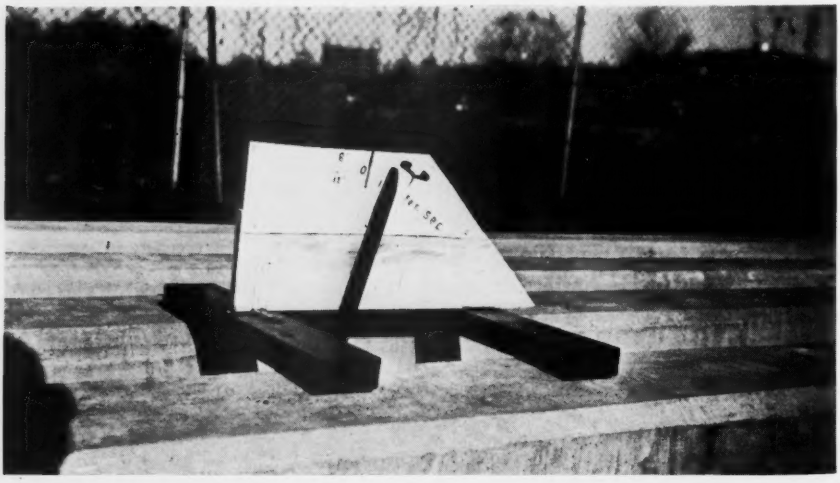
Operator, Putnam, Conn., Sewage Treatment Plant

The indicator shown in the sketch is rather crude, but answers a useful purpose. It enables the operator to tell, at a glance, whether the sewage is flowing through his grit chambers too fast, too slow, or within the operating range.

It was made from a broom handle 48 in. long, a 5-in. galvanized disc, two 24-in. lengths of 2 by 4s, one ⅞-in. board, 10 in. wide by 24 in., four corner braces, 18 wood screws and one 2½-in. belt.

To find and mark "operating range" on dial, adjust sewage flow to desired velocity, and mark dial while meter is in operation.

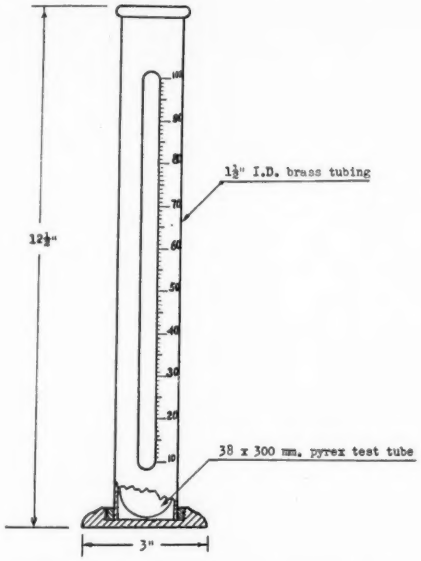
If indicator is too sensitive to velocity changes, cut down size of disc or place screw hook in indicator lever about midway between water line and where it is hinged and add weights until the desired results are obtained.



METAL CONTAINER FOR SETTLEABLE SOLIDS TUBE

By Don Bloodgood
Superintendent, Indianapolis, Indiana

The brass tube and glass test tube are of standard size as given in the figure below. The calibrations are easily made, allowing for the rounded bottom. The use of these metal covered glass cylinders has materially cut down the breakage.

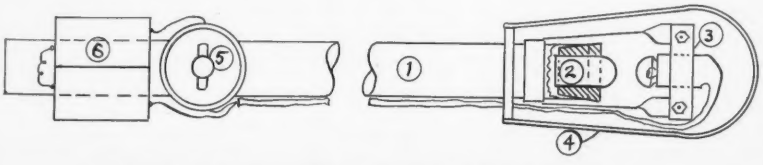


Metal Container for Settleable Solids Tube.

PERISCOPE

By W. A. Sperry
Superintendent, Aurora Sanitary District

This periscope design has the advantage of simple construction and lightness. The tube (1) is made of 1¼-in. galvanized iron "speaking tube." It is light and quite rugged. The window (2) is the end of a test tube in a rubber stopper held in place and sealed with friction tape. The flashlight bulb (3) is held with a yoke made of strips of galvanized iron and small nuts. The whole lower end of the tube is protected by an ordinary wire light guard (4). A snap switch (5) and two flashlight cells (6) complete. The wiring at the bulb is carried in a piece of rubber tubing sealed with friction tape and hot asphalt. The wires are rubber covered and bound to the tube at intervals of one (1) foot, which calibrates the tube.



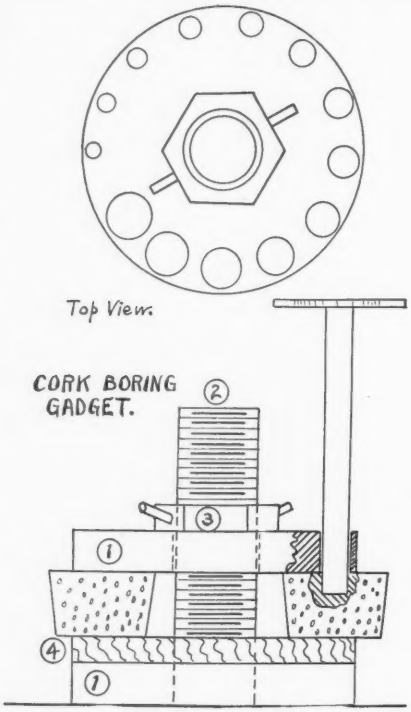
Design for a Periscope that is simple and very light to handle.

CORK BORING GADGET

By W. A. Sperry

Superintendent, Aurora Sanitary District

This simple and handy gadget costs about one dollar for the materials. Part (1) consists of two plain 6-in. cast-iron flanges. One is used for the base. The other is drilled to suit cork borer tubes as shown. The center hole in the top plate slips easily



Elevation: Showing manner of use.

past the threads of the 1-in. pipe (2). (3) is an ordinary lock nut with small wings to facilitate clamping the cork to be bored. An extra cork is used to balance the plate. (4) is a soft wood disk to protect the cork boring tube. The set of borers may be kept "nested" in the top of the center pipe.

B.O.D. TABLE TOPS

By Harry Kramer

Jr. San. Chemist, Sanitary District of Chicago

While not exactly a gadget, nevertheless it may save some chemist's apron. At the S. D. C. Main Laboratory we have a lead-top table on which we treat B.O.D. samples. It was originally intended to burn a lead bead around the outer edge of the table top so

that the bottles could be washed free of excess chemicals after treating, by means of a hose. The lead bead of course was to keep the wash water from running over the edge of the table to the floor. Temporarily, and maybe permanently, we got some automobile weatherstrip, which is a strip (20 ft. for 50 cents) of sponge rubber ¾-in. wide and ⅜-in. thick, with an adhesive material on one face. By heating the lead and warming the adhesive we have a nice tight waterproof seawall around the edge of the table which will turn back a ⅜-in. tide.

MAINTENANCE OF PUMPING STATIONS AND FORCE MAINS *

By John V. Lewis

Director, Division of Maintenance and Operation, Department of Public Works, Rochester, New York

The maintenance of pumping stations and force mains is a problem which probably confronts almost all operators of sewage treatment plants, without regard to size. Pumping stations and force mains may be a part of the plant proper or they may be isolated and situated in one or many different locations throughout a city, town, or sewerage district. This is the case at Rochester where the city has in service nine lift stations of which six stations are equipped with centrifugal pumping units and three stations with pneumatic ejectors. Over a period of more than twenty years, the latter type of lift station has largely been superseded by stations in which are installed centrifugal sewage pumps of various makes, types, and capacities. The comments set forth in this brief paper will therefore apply to this type of station and particularly those which operate on what might be called "intermittent" duty.

Each station at Rochester is visited once or twice daily by a maintenance crew, whose duty it is to carry out the following procedure:

(1) Clean stationary racks or screens.
(2) Check and provide, if required, lubrication for pumping units.
(3) Adjust sequence of operation of units.
(4) Determine, if possible, any abnormal conditions which may exist with respect to the operation of pumps, motors, control, etc.

The design of sewage pumping units has today advanced to the point where if this simple procedure is strictly followed difficulties in operation will be largely obviated.

Insofar as the pumps are concerned, lubrication is probably the most important factor to be considered. Most modern pumping units are equipped with anti-friction bearings of either the ball or roller type and intended to be grease lubricated. It is important that the lubricant be of high quality; *i.e.* one which will not saponify in the presence of moisture or disintegrate under heavy pressure. If the proper kind and

* Presented at the Fall Meeting of the New York State Sewage Works Association, Elmira, Oct. 16, 1937.

consistency of lubricant is provided, bearings will function as intended over a period of years and without expense for renewal and maintenance.

Second to the matter of lubrication is maintenance of shaft wearing sleeves. They should be of the proper diameter and should have a smooth surface, with a suitable packing. The rotative speed of the pumping units and the character of sewage determine the materials which will give the best service and no hard and fast rule can be laid down. It is best to select the lubricant and packing by practical tests.

At Rochester, wearing sleeves which were made of various metals such as alloy bronze, heat-treated steel, and cast Monel metal have been tried; also various kinds of metallic and fibrous packings. In general, either alloy bronze or Monel metal sleeves and a reasonably soft and graphite-impregnated packing give the best results.

The tap water connection to the stuffing box of the pump will sometimes overcome wearing sleeve and packing difficulties. However, from the standpoint of possible contamination of the source of clear water, a separate automatic pumping unit must be provided. This extra equipment complicates the installation and is not justified except in the larger stations.

Clogging of pumps can be prevented by the installation of and proper raking at intervals of coarse racks of suitable spacing, set at the entrance to the wet well. Sewage pumps having sufficient size and impeller clearance will give very little clogging difficulty, even in intermittent operation.

What has been previously stated concerning the lubrication of pumps applies equally well to the bearings of intermediate shafts, in the case of vertical type units, and also to the prime mover.

Electric motors for driving sewage pumps are usually equipped with ball or roller bearings, which if properly lubricated should give no trouble in operation. Insulation of motors should be given a periodical test, even if the insulation is of the so-called "moisture-proof" type. This procedure often prevents burn-outs and subsequent replacement at considerable trouble and expense. Occasionally such difficulties will be experienced and the practice at Rochester is to have at hand one spare motor for the different units installed in the various pumping stations.

One of the greatest sources of annoyance and expense has been the failure of electrical controlling apparatus to function as intended. Experience has shown that the failure is due to two causes; primarily, to insufficient capacity of controller or starter, irrespective of the manufacturer's rating; secondly, to improper materials in the contacts of the apparatus, which materials must meet the duty imposed, especially when such apparatus is not under constant observation. These two factors have had much to do with the various burn-outs of motors in the several pumping stations. The problem became so acute several years ago that almost all controlling equipment was replaced by apparatus of a different make and larger capacity. Further, extensive investigation

was carried out to obtain and test in actual use serviceable contacting materials. After a time, a material known as "Elkonite," which is the trade name of a copper-tungsten "diffused" metal, was obtained as a facing for the hard-drawn copper contacts then in use. In one station where the sequence of operation of pumping units is at intervals of three to ten minutes daily, the first set of contacts which were faced with "Elkonite" have shown no deterioration after three years of service. The controllers at all six pumping stations have now been provided with contacts faced with Elkonite metal and not a single failure of the controllers to function properly nor a consequent burn-out of the motors has occurred. Previously, in spite of the use of thermal overload and open phase relays, such damage was frequently experienced.

In the matter of equipment for actuating the operation of the controllers on rise and fall of sewage level, experience has shown that both float and air-pressure units are satisfactory. Where the "in" and "out" levels can be allowed to vary slightly, air-pressure control is more simple and equally as satisfactory as float control.

It is important that every pumping station and its equipment, regardless of size, location, and duty, should be kept clean, properly painted, and be suitably ventilated if possible. Such measures will add years to life of pumps, shafting, bearings, motors, controllers, meters, etc.

It is the practice at Rochester to post in each station a weekly report sheet upon which the maintenance crew indicate their arrival and departure each day; the work performed; and the operating conditions observed. Abnormal conditions are immediately reported to the foreman in charge of sewage treatment plants and, if necessary, to the office of the Director of Maintenance and Operation.

The suggestions for maintenance of centrifugal pumping units and their appurtenances apply equally well to pneumatic lifting and sludge pumping equipment. If suitable lubrication and routine attention is furnished, difficulties in operation will be kept to a minimum.

Properly designed force mains require very little attention. The larger sizes of force mains in use at Rochester are equipped with suitable blow-offs at the low point. The small diameter mains are designed to have a sufficient velocity of flow when in use so that the sewage will scour the main and keep it clean. On rare occasions, water from fire streams has been introduced into the wet wells of the several stations and all pumping units placed in operation for a short interval to flush the main. If the discharge nozzle of the pumps is not provided with a permanent indicating pressure gauge, pressure taps are provided and an occasional check-up with a portable gauge shows the presence of a potential stoppage or a gradual accumulation of deposits, which should be located and removed.

Some force mains include metering apparatus and the same precautions and attention heretofore mentioned apply. A definite routine for cleaning and checking operation should be established and maintained.

In conclusion, it can be stated that, given a correct design of pumping stations and force mains, with modern equipment installed, adequate lubrication and systematic attention, difficulties in operation will be small.

Discussion

By Wm. A. Ryan

Sanitary Chemist, Rochester, N. Y.

There is little that I may add to Mr. Lewis's paper. Pumping stations appear to function smoothly if the moving parts are oiled or greased at regular intervals. Two men should visit an underground station together, as there is always an element of danger when one man is left alone in a manhole or underground station.

The plot or lawn around a pump station should receive the same attention that is given to plant grounds. There is greater need of frequent painting in underground stations than in the overhead type.

Oily rags, rakings from the rack, etc., should be removed at frequent intervals. If oily rags are to be held for any length of time, they should be kept in covered metal containers. This should also apply in the case of clean rags, as moisture is always present.

The best type of grease and oil should be purchased and used; it is poor economy to attempt to cut costs on oil or grease. The stations should be well ventilated, the wall ladders leading to the underground stations should be kept as free as possible of moisture and fungus growth as there is danger of slipping on wet ladders.

The manhole covers and doors should be locked in order to keep out intruders. In the case of ejector stations, spare parts should be available; the parts that require replacement will soon be discovered by experience.

A portable pump, operated by a gasoline engine, is essential as part of the city or village equipment, because power failures do occur and the sewage must be pumped out of the station. Regular visits, and utmost cleanliness, are by-words of success in operating pumping stations.

Editorial

SEWAGE AND THE NATIONAL RESOURCES COMMITTEE

The National Resources Committee has just released a report "Drainage Basin Problems and Programs" which contains a summary of the reports of forty-five drainage basin committees, comprising a total of about 550 men. The present report follows two earlier reports, which have been revised and brought up to date, in accordance with the request of President Roosevelt dated August 20, 1937.

The major part of the report deals with questions of flood control, irrigation, water power, TVA program, rivers and harbors, and other major drainage basin problems, but it also includes a survey of requirements for water pollution abatement, and recommendations for investigations of pollution. Public water supply and pollution abatement are considered to be primarily of local interest, and therefore financing of such projects is considered a local problem, subject to such loans and grants as may be available through existing agencies (PWA). A six-year program for conservation of resources and also for abatement of pollution is presented. For the conservation program a total of $891,091,000 is proposed for the six-year period, most of which is allocated to irrigation, flood control, rivers and harbors and TVA program. For the six-year pollution abatement program, $566,765,000 is allocated to water supply, with 2,678 projects, and $667,011,000 to pollution abatement and sewerage, with 3,484 projects. Projects are numbered according to drainage basins; for example, $215,852,000 is allocated to the North Atlantic basin, with 270 projects, and $104,155,000 to the Ohio basin, with 272 projects. Only very general reference is made to the needs for sewage treatment in any of the drainage basin, but it is expected that specific recommendations will be made in the reports of the 45 drainage basin committees.

The present report contains recommendations for investigations of pollution abatement, including $1,150,000 for the first year, plus an additional $1,000,000 later, for "studies to obtain quantitative information regarding sources and effects of domestic and industrial waste pollution on streams, lakes and coastal waters and to evolve comprehensive basin-wide plans for the abatement of such pollution" in drainage basins throughout the U. S.

Recommendations also include the appropriation of $235,000 for the first year, and $385,000 to complete, for a "study to find economical methods of treatment or preventing the entrance into water-courses of various industrial wastes, especially mining wastes, oil field brines and sulphite liquor from paper pulp plants" in some 18 drainage basins.

"For the most part these investigations should be carried out with local funds, but cooperation by Federal agencies may be desirable where regional and interstate considerations are important."

It is suggested that Federal participation in any pollution-abatement program should be limited to

1. Loans and grants to public agencies, and loans to nonpublic agencies (industries).
2. Encouragement of uniform laws and practice.
3. Coordination of State and local activities.
4. Encouragement of interstate compacts.
5. Establishment of standards of water purity.
6. Research on methods of treatment or proper disposal of various wastes.
7. Studies and surveys in cooperation with local agencies.
8. Coordination of the pollution-abatement program with broader programs for water control use and with public works.

In earlier reports, establishment of a "Potomac River Conservancy District" was recommended, as a demonstration drainage basin unit for developing by trial and error the practicability of the recommendations of the committee for abatement of pollution. In the July, 1935, report a sum of $15,000,000 was requested for this work, of which it was estimated that approximately one-third to one-half might be reimbursed by local payments. In the May, 1937, report, this was revised to $11,790,000, as a result of the installation of sewage treatment works. Federal participation was estimated as not over $7,000,000.

The present report also recommends the establishment of the Potomac District, without specific estimate of the cost. In the May, 1937, report, costs were as follows:

Construction of sewage treatment works	$ 4,850,000
Construction of industrial waste treatment works	2,700,000
Prevention of acid mine waste	140,000
Conservancy dams	1,500,000
Administrative and engineering	950,000
Special investigations	150,000
Contingencies	1,500,000
Total	$11,790,000

The industrial wastes listed included those from tanneries, paperboard, artificial silk, dye works, paper mills, tin plate, and textile mills. Many important types of wastes, such as those from packinghouses, distilleries, coke plants, sulfite mills, and steel pickling plants are apparently not present in this area.

The report stresses the industrial waste problem and suggests that if trade associations would spend as much money in the investigation and development of methods of treating and recovering trade wastes as they spend in fighting legislation, more fortunate and gratifying results would be accomplished.

In the larger aspects of pollution abatement in various drainage basins, particular reference is made to objectionable conditions at or near Philadelphia, Pittsburgh, New York, Wheeling, Chester, Cincinnati and Louisville. It is stated that the following expenditures, in millions, will be needed to complete sewage treatment in the various metropolitan areas: New York—135; Philadelphia—30; Pittsburgh—30; Norfolk—8; District of Columbia—4; Calumet region in Indiana—9. For St. Louis, sewerage facilities to the extent of 10 millions of dollars should be provided in due time. It is not stated whether this includes sewage treatment, or whether the discharge of ground garbage into the Mississippi at St. Louis has the Committee's approval.

This report should attract wide attention among sanitary engineers and should create interest in the forthcoming reports from the various drainage basin committees, of which some five or six have been issued. The Potomac District, if established, will be watched with intense interest by those who have similar problems throughout the country. If research on industrial wastes is undertaken, the Subcommittee on Water Pollution should seek the advice and cooperation of representative authorities throughout the U. S., since the Subcommittee is rather restricted to Eastern and Governmental authorities.

The report reiterates the need for integration of present conflicting policies (somewhat overworking the word "integrated" on page 7). In this effort the Committee should have the support of all those who desire abatement of the pollution of our public waters.

Abel Wolman is the guiding genius of the Committee report, and his ability and broad experience are well known to all readers of this Journal. Further information from the Committee will be awaited with great interest.

F. W. M.

Correction: In the paper "Recent Laboratories for Large Sewage Treatment Plants," page 73 of the January, 1938, issue, it was stated that plans for the Cleveland laboratory were furnished by George O. Jones; this should have been Frank Woodbury Jones, of the office of George B. Gascoigne and Associates, Cleveland and New York City.

Proceedings of Local Associations

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Tenth Annual Meeting

New York City, January 20–22, 1938

The tenth annual meeting of the New York State Sewage Works Association was held in New York City, January 20–22, 1938, with headquarters at the Hotel McAlpin. Three hundred and twenty members and guests were registered, including 85 outside of New York State from fourteen association affiliates of the Federation.

C. George Andersen (Rockville Centre), Henry Ryon (Albany) and William E. Stanley (Ithaca) were elected to the *Executive Committee* for a period of three years; and F. Arthur Cary (Fairport) was elected to fill the unexpired term of Harry Eustance who resigned. Fred J. Biele (Huntington) was elected *President* and Newell L. Nussbaumer (Buffalo) *Vice-president.* A. S. Bedell, State Department of Health, Albany, N. Y., was reappointed *Secretary-Treasurer,* and J. C. Brigham (Albany) was appointed *Assistant Treasurer.*

The program was arranged so that the members of the Sewage Works Association were able to attend all the Thursday sessions of the Sanitary Engineering Division of the A. S. C. E. And in like manner the members of the A. S. C. E. attended the technical sessions of the N. Y. S. S. W. A. on Friday and the joint inspection trip on Saturday.

Following the technical sessions of the A. S. C. E. on Thursday, the two groups gathered for a joint dinner, at which Professor Henry E. Riggs of the University of Michigan and president of the American Society of Civil Engineers, gave a very stimulating address.

At the general business meeting on Friday, it was noted that the Association now had a membership of over 500 and that the Long Island Section had a membership of 108, and a new section known as the Genesee Valley Section has just been approved.

A resolution with reference to pending State legislation on stream pollution control was unanimously adopted. Also a resolution with reference to desirable modifications of the law on the financing of non-debt revenue bonds was unanimously adopted.

At the technical sessions in the morning, Arthur S. Bedell, Secretary-Treasurer of the Association, gave a brief paper on "The First Decade of the New York State Sewage Works Association." C. George Andersen, Superintendent of Sewers of Rockville Centre, gave an illustrated paper on "Sludge Digestion and Inspection of Tanks at Rockville Centre."

At the luncheon, Kenneth Allen Memorial Awards for 1937 were presented to Charles L. Walker, Cornell University, Ithaca, N. Y., for the most meritorious paper of a technical and research nature and to

Wellington Donaldson, Department of Public Works, New York City, for the best paper on sewage plant operation presented during the year.

George B. Gascoigne, of Cleveland, O., was the principal speaker at the luncheon and gave a most interesting talk on the subject "Better Sewage Works."

At the afternoon session the following papers were presented: Wellington Donaldson, Sanitary Engineer, and Henry Liebman, Mechanical Engineer, Department of Sanitation, New York City, "The Utilization of Sludge Digestion Gases at the Coney Island Sewage Treatment Works"; Earle B. Phelps, Professor of Sanitary Science, Columbia University, New York City, "Biochemistry in Sewage Treatment"; R. H. Gould, Chief Engineer, Bureau of Sewage Disposal and Intercepting Sewers, Department of Sanitation, New York City, "Ward's Island Sewage Treatment Works Goes into Service."

Announcement was made by Professor C. L. Walker of Cornell University and Professor L. V. Carpenter of New York University of the two weeks' courses for sewage works operators to be taken at their respective institutions this spring.

On Saturday a joint inspection trip by bus was enjoyed by some 120 persons to the Ward's Island sewage treatment plant and the Bronx sewer tunnel grit and screen chamber of New York City.

The spring meeting of the association will be held at Buffalo, N. Y., June 3 and 4, and the fall meeting will be a joint meeting with the New England Sewage Works Association with manufacturers' exhibits at Hotel Bond, Hartford, Conn., October 6, 7, 8, 1938.

Resolutions Unanimously Adopted at the Tenth Annual Convention of the New York State Sewage Works Association Held in New York City, January 20–22, 1938

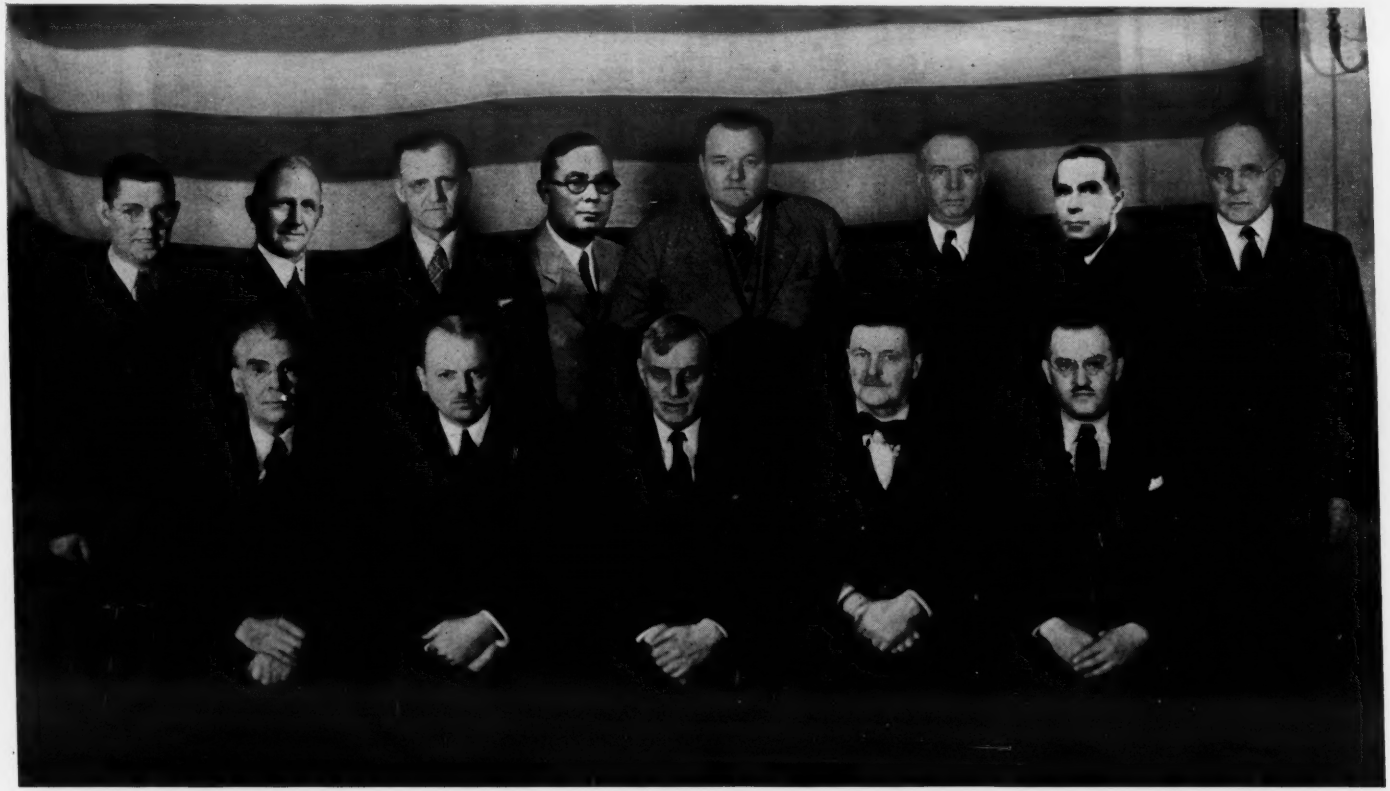
Whereas the elimination of pollution of the waters of the State of New York has progressed rapidly in recent years under the force of public sentiment and opinion, and

Whereas the general program of such elimination should be brought to a successful completion as soon as possible in the interest of public health and welfare, and

Whereas there is a need for the strengthening of existing laws to give this program the impetus necessary to accomplish such purpose,

Now, Therefore, Be It Resolved: That this Association in convention assembled recommends the passage of reasonable legislation to clarify existing laws, eliminate conflicting provisions thereof, and to give the State Department of Health such funds and added authority as may be required to bring to a speedy conclusion the elimination of pollution of the waters of the State.

Whereas it is believed that the financing of sewage and water projects by means of non-debt revenue bonds will make possible the construction of water and sewer systems which are urgently needed but otherwise impossible to secure, and



Standing (left to right): Linn H. Enslow (1936); John F. Skinner (1931); A. F. Dappert (1933); C. A. Holmquist (1930); L. L. Luther (Secy. Long Island Section), R. C. Wheeler (Vice-President, 1935, Auditor and Chairman Legislative Committee); E. B. Besselievre (1934); A. S. Bedell (Sec.-Treas.).

Sitting (left to right): Earle B. Phelps (1932); Charles C. Agar (1937); Charles A. Emerson (Chairman, Federation of Sewage Works Associations); Fred J. Biele (1938); Morris M. Cohn (1935).

Note: Kenneth Allen (1929) deceased. Dates are dates of holding office as President.

Whereas the issuance of such bonds is permitted under Sections 400 to 416, inclusive, of Article 14–C of the General Municipal Law of the State of New York, but with the restriction that they be purchased only by the United States of America or any agency or instrumentality thereof,

Now, Therefore, Be It Resolved: That this Association in Convention assembled go on record as recommending that this law be amended to the end that such bonds may be purchased by others than the United States of America.

A. S. BEDELL,
Secretary-Treasurer

THE FIRST DECADE OF THE NEW YORK STATE SEWAGE WORKS ASSOCIATION *

BY A. S. BEDELL

Secretary-Treasurer, New York State Sewage Works Association. Chief, Bureau of Sewage and Waste Disposal, New York State Dept. of Health

This meeting is the Tenth Annual Convention of the New York State Sewage Works Association. It has been thought advisable, therefore, for us to make sure our birth has been properly recorded and the history of our early youth written down, bearing in mind we are beginning our tenth year and not completing it.

The history of the New York State Sewage Works Association is closely bound with that of the Federation of Sewage Works Associations which as you know is also celebrating its tenth anniversary this year. Although the record is not clear, it was probably at the instigation of the Federation that the late Kenneth Allen, Sanitary Engineer of the Board of Estimate and Apportionment of the City of New York, sent out a call for a preliminary organization meeting in New York City on March 26, 1929.

At that meeting a committee on constitution and by-laws and a membership committee were appointed. Furthermore, each of the earnest group of fourteen men donated five dollars toward organization expenses in the matter of postage, etc.

The membership committee under the chairmanship of Earl Devendorf, Associate Director of the Division of Sanitation of the State Health Department, worked up a mailing list of some two hundred names of municipal officials, consulting engineers and sewage plant operators. When the final organization meeting, or first annual meeting of the Association, was held in the State Capitol at Albany on May 4, 1929, word had been received from 83 men that they wished to become charter members of the proposed organization. Eventually there were by July first 152 charter members, a rather good weight for a two months old baby with a five weeks' pre-natal history.

* Presented at Tenth Annual Meeting of the New York State Sewage Works Association, New York City, Jan. 21, 1938.

The twenty-three men present at the first annual meeting adopted the Constitution and By-Laws and appointed a committee on nominations for the first Executive Committee, concerning which there is an amusing incident worth recording. It was quite evident that the temporary chairman, Mr. Allen, had appointed a nomination committee of five, all of whom we would naturally expect to become officers of the Association. Therefore, the youngest member of the committee having the courage of his convictions, assumed the chairmanship and immediately put on the slate the names of the other four members of the committee. So that is how H. B. Cleveland, Morris Cohn, John Skinner, and Russell Suter nominated themselves with five others for the first Executive Committee. Kenneth Allen was elected the first president and Charles A. Holmquist, vice-president. The writer was appointed secretary-treasurer with the inevitable result—a life sentence, which, however, he seems to enjoy.

The aims of the organization as set forth in the Constitution are worth repeating at this time in order to determine if we are living up to our ideals.

Section 1. The advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of works for the collection and treatment of these wastes.

Section 2. The promotion and encouragement of improved waterways sanitation, through the same measures.

Section 3. The encouragement of a friendly exchange of information and experience among its members, and other interested persons, by an annual convention of its members, the publication of proceedings of its meetings, affiliation with the Federation of Sewage Works Associations, and participation in the activities of that organization.

I think we can safely say we have had a considerable measure of success in our start toward accomplishing most of these aspirations. We hold three meetings a year, at one of which our manufacturers display very attractive and instructive equipment and materials exhibits.

Approximately 80 per cent of the papers presented at our meetings are found by the editor of the *Sewage Works Journal* worthy of publication. Our plant operators realizing the value of "friendly exchange of information and experience" have formed two local sections which hold quarterly meetings. The largest and oldest group is the Long Island Section with a membership of 108 established through the inspiration and persistent efforts of Lawrence Luther and Wellington Donaldson. The Executive Committee has just approved the formation of the Genesee Valley Section. At the organization meeting of this section thirty-five persons were present, of whom ten were members of the parent body. A third group is now being organized in Western New York.

The Association, under the leadership of Professor Earle B. Phelps, has actively sponsored two schools for sewage works operators; one at Union College in January, 1931, and one at Cornell University in April, 1932. It was the hope that eventually this work would be taken

over by some educational institution. This hope appears now to be realized, since Cornell University is planning a two weeks course for plant operators next month, and New York University and Rensselaer Polytechnic Institute have programs in preparation. The Association continues to cooperate with the Mayors Conference and State Health Department in the biennial three-day conference schools now held in various parts of the State.

In sewage research we have had a standing committee for several years which has acted as coordinator and has sponsored a number of research investigations at individual sewage plants. With the new joint research and sanitation laboratory of New York City and New York University up at University Heights, it is hoped that the activities of this committee may be greatly extended.

By suitable and attractive awards the Association endeavors to stimulate interest in and recognize the merit of the activities of the members of the Association. The first award established was the Kenneth Allen Memorial Award, a cast bronze plaque, a portrait in relief of the late Kenneth Allen, founder and first president of the Association. Two awards are made annually; one for the most meritorious paper of a research nature presented at the meetings during the year, and one for the most valuable paper on plant operation showing evidence of work and study outside the normal routine.

A second award was established two years ago known as the Rating Award, a large silver loving cup. This award is granted annually to the operator presenting the best routine annual report on operation in accordance with the detailed schedules prescribed by the Committee and is designed to elevate the standards of plant operation and stimulate the preservation of essential operating data in a form suitable for dissemination.

The third award in the form of three framed certificates is granted to the three best gadgets displayed by plant operators at a designated meeting each year.

The Legislative Committee this year has seen the fruit of its efforts in the matter of licensing plant operators. With the passage of favorable legislation at the 1937 session of the State Legislature, the Public Health Council promulgated rules and regulations setting up qualifications for sewage works operators. These regulations went into effect on October 1, 1937, and prescribe the qualifications for operators appointed after that date. The various plants are classified according to tributary population and type of treatment and three grades of operators are established.

As to membership, it is interesting to note that in nine years time we have grown from 152 charter members to a paid up membership of 460 this past year, with a sufficient number in arrears who if paid up would raise the total to over 500. We have 22 associate members (manufacturers of sewerage equipment) and about one-third of our new members each year are plant operators or sewer superintendents. We are now one of 25 affiliates of the Federation of Sewage Works

Associations. At the time of our genesis we were the eleventh child of the Federation.

While I believe we have exceeded our early aspirations or anticipations in this short history of our Association as to membership, type of meetings, and increase in *esprit de corps* and individual morale among plant operators, we cannot rest on our oars for there is much to be done in intensive effort along lines already established. It seems to me that one of the most important projects for the future is to impress on the operator the importance of his work in plant operation and prevention of stream pollution, the need for making careful daily tests and records of plant operation and for recording general observations. By these means the operator opens the way for further research and better plant design with resultant economies to our communities and cleaner waterways.

OHIO CONFERENCE ON SEWAGE TREATMENT

Eleventh Annual Conference

Cincinnati, Ohio, October 19–20, 1937

The Eleventh Annual Conference on Sewage Treatment was held at the Netherland Plaza Hotel in Cincinnati on October 19–20, 1937. The total registered attendance was 135, exceeding the number attending in past years and offering considerable encouragement to the conference officials.

Following the usual annual procedure, the Ohio Conference on Water Purification and the Ohio Conference on Sewage Treatment were held at the same place and during the same week, this year the Sewage Conference preceding the Water Conference and each devoting two days to business and technical sessions. The retiring officers were: G. A. Hall, Marion, *Chairman;* M. W. Tatlock, Dayton, *Vice Chairman;* J. H. Wenger, Westerville, *Treasurer,* and J. J. Wirts, Cleveland, *Member of Executive Committee.* The new officers elected were: J. H. Wenger, Westerville, *Chairman;* J. J. Wirts, Cleveland, *Vice Chairman;* F. E. Harroun, Akron, *Treasurer,* and Ben H. Barton, Findlay, *Member of the Executive Committee.* By the constitution of the organization, the secretary is a representative of the State Department of Health, appointed by the chief engineer of the department.

The first technical session was opened on the afternoon of the first day with an explanation of recently adopted "Regulations for Licensing Water and Sewage Plant Operators" by F. D. Stewart, principal assistant engineer, Ohio Department of Health. The discussion which followed indicated that generally the plan was favorably received and was welcomed as a means for improving conditions of plant operation throughout the state.

A paper "The Design of a Small Sewage Treatment Plant" was presented by W. H. Knox, assistant engineer, Ohio Department of

Health. As indicated, consideration was limited to small works in view of the fact that usually the small municipality cannot well afford a thorough engineering study and will seldom receive one. An endeavor was made to outline basic design and capacities and essential features of devices that may be incorporated in types of plants which are suitable for serving small comunities.

C. C. Hommon, superintendent of the sewage treatment plant in Canton, in his paper on "The Relation of the Part Time Technical Supervisor to the Sewage Treatment Plant Operator and to the Municipal Official," discussed the operation and administration problems encountered at the small municipal works and by example pointed out how the supervisor may function to advantage in assisting in the solutions of these.

The group discussions which were inaugurated in 1935 were continued. Choice of attendance of groups having as their representative topics "Administration of Sewage Works," "Activated Sludge Treatments," "Sedimentation and Sludge Digestion," and "Sewage Filtration," were given. The leader of each group, or one designated by him, summarized the discussion at a breakfast meeting on the following morning. These group discussions are a popular feature of the conference and the consensus of opinion seems to be that more time can well be devoted to them.

At the banquet on the evening of the first day, the conference members were favored with an address of welcome by Honorable Russel Wilson, Mayor of Cincinnati, followed by an address by Mr. Hudson Biery, Chairman of the Stream Pollution Committee, Cincinnati Chamber of Commerce, on "Interstate Stream Pollution Control." Mr. Biery has been very active in efforts to promote federal legislation effecting states in the Ohio River valley and very ably presented the accomplishments that have been made and the problems yet faced.

Following the breakfast meeting on the second day, J. E. Root, Director of Public Utilities, Cincinnati, presented a paper on "Sewerage and Sewage Disposal at Cincinnati." He described the problems which have been and are being faced by the city and the accomplishments of sewage collection which have been made to date, as well as the efforts which are being put forth to continue by a comprehensive program toward an ultimate solution of the sewage disposal problem for the city.

J. K. Hoskins, senior sanitary engineer, United States Public Health Service, in charge of the Stream Pollution Investigation session at Cincinnati gave a most interesting paper on "Planning the Organization and Conduct of Stream Pollutions Survey." Much information was set forth which will be helpful to all sewage plant operators and sanitary engineers in problems which they may have.

Of particular interest to the sewage plant chemist was the paper given by Charles F. Hauck, on "Interference of Acid Iron Waste in Sewage Analyses at the Cleveland Southerly Sewage Treatment Plant." Analytical data which he had accumulated in his laboratory was presented in a most thorough manner.

The final technical subject of the conference was a "Progress Report on Sewage Filtration." This report was presented by M. W. Tatlock, Dayton, Chairman of the committee on research. Other members of the committee were: Floyd G. Brown, Marion; T. C. Schaetzle, Akron, and G. E. Flower, Cleveland. Discussion of papers pertaining to trickling filter loadings and to filter media for trickling filters at the 1936 conference led to the appointment of the above committee to accumulate further data with reference to the design, operation and accomplishments of such units. An interesting feature of the report was the accomplishments of high rate filtration on an experimental trickling filter unit.

As has been customary, an annual report of the conference, including the technical papers and discussions will be prepared and published. Each registrant will receive a copy of this report. Due to the fact that it has become necessary for this publication to be financed from conference funds rather than from state funds, a nominal charge is made persons not having registered at the conference. Announcement will be made when the report is ready for distribution.

BRUCE M. MCDILL, *Secretary*

IOWA SEWAGE TREATMENT CONFERENCE

Nineteenth Annual Meeting
and the
First Iowa School for Sewage Works Operators

Iowa State College, Ames, Nov. 29 to Dec. 3, 1937

For the first time a School for Sewage Works Operators was held in conjunction with the annual Iowa Sewage Treatment Conference. This school was one week in length and covered, as fully as the time available would permit, a study of the basic principles of sewage treatment and the fundamentals and problems of plant operation.

Subjects included in the instruction were as follows:

The Significance of Sewage Treatment Today.
Characteristics of Sewage and Their Relationship to Treatment.
Sewage Flies, Worms and Lower Forms of Life in Sewage.
The Efficient Use of Grit Chambers and Bar Screens.
Sewage Tanks—Why and How They Work. Activated Sludge Operation.
Trends in Chemical Treatment of Sewage.
Principles of Sewage Filtration.
Experiments on High Rates of Filtration.
The Operator and His Work.
The Bacteriology of Sewage Treatment.
Sewage Plant Mechanization.
Care and Maintenance of Municipal Sanitary Works.

Control of Sewage Plant Operation-Tests.
Sewage Plant Records and Operating Reports.

City officials and engineers joined superintendents and operators in discussing general and administrative problems at the Sewage Treatment Conference on December 2 and 3. A total of 120 men registered for the school and conference. The program included the following topics:

The Liabilities of Municipalities for Patent Infringement.
Problems of Administration of Municipal Sanitary Works.
Operation of the Iowa City Sewage Treatment Plant.
Handling Storm Sewage at Council Bluffs.
Gas and Disease Hazards at Sewage Works.
How to Avoid Liability for Nuisance Conditions.
Trends in Industrial Waste Treatment in Iowa.
The Proposed Waterloo Sewage Works.
Plans for the Des Moines Sewage Works.
Pumping Problems of the Iowa Great Lakes Sewage Works.
The Future of Sewage Treatment in Iowa.

Iowa Wastes Disposal Association

Eleventh Annual Meeting

Dec. 2, 1937—Ames, Iowa

The eleventh annual meeting was called to order by President W. E. Galligan at 4:00 p.m., December 2, following the afternoon session of the Iowa Sewage Treatment Conference. A short business session was held concluding with an election of officers. The group then adjourned to the College Memorial Union for a joint dinner meeting with the Iowa Municipal Employees Association. Following the dinner and entertainment, Toastmaster J. H. Ames, City Manager of Ames, introduced Lyman S. Moore of the International City Managers Association, Chicago, who gave an address on "Retirement and the Merit System," and A. S. Hansen, Consulting Actuary, Chicago, who spoke informatively on "The Illinois Pension Law." The meeting concluded with a brief discussion of what was desired in Iowa by way of pensions and civil service, and means to this end.

Officers selected for the year 1938 were as follows:

W. E. Galligan, Ames.....*President*
Elmer E. Dye, Mason City.....*Vice-President*
Lindon J. Murphy, Ames.....*Secy.-Treas.*
Stanley Baker, Newton.....*Director*
A. J. Sedlacek, Pocahontas.....*Director*
Earle L. Waterman, Iowa City....*Representative to Board of Control, Federation of Sewage Works Associations*
A. H. Wieters, Des Moines.....*Representative to Board of Control, Federation of Sewage Works Associations*

LINDON J. MURPHY,
Sec.-Treasurer

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

MINUTES OF THE ANNUAL MEETING OF THE BOARD OF CONTROL

The Annual Meeting of the Board of Control of the Federation of Sewage Works Associations was held at Leeds Restaurant, 25 East 40th Street, New York City, on Friday evening, January 21, 1938.

The business meeting, following a dinner attended by members of the Board, was convened at 8 p.m., Chairman Emerson presiding. The roll call indicated the following to be present in person:

Name	*Representing*
Charles C. Agar	New York State Sewage Works Association
H. G. Baity	North Carolina Sewage Works Association
John H. Brooks	New England Sewage Works Association
Wm. W. Buffum	Member-at-Large
W. W. DeBerard	Central States Sewage Works Association
C. A. Emerson, Jr.	Pennsylvania Sewage Works Association
Linn H. Enslow	New York State Sewage Works Association
Gilbert R. Frith	Georgia Water Works and Sewage Operators' Association
F. Wellington Gilcreas	New England Sewage Works Association
C. G. Gillespie	California Sewage Works Association
Frank Woodbury Jones	Ohio Sewage Works Conference
Dana E. Kepner	Rocky Mountain Sewage Works Association
A. P. Miller	Federal Sewage Research Association
F. W. Mohlman	Editor
H. E. Moses	Pennsylvania Sewage Works Association
Wm. M. Piatt	North Carolina Sewage Works Association
Willem Rudolfs	New Jersey Sewage Conference
Earle L. Waterman	Iowa Wastes Disposal Association

Present in person, acting as proxy:

Name	*Representing*
R. A. Allton (for C. D. McGuire)	Ohio Sewage Works Conference
A. S. Bedell (for Abel Wolman)	Maryland-Delaware Water and Sewerage Ass'n
Gordon M. Fair (for H. J. Darcey)	Oklahoma Water and Sewage Conference
A. E. Griffin (for W. J. Orchard)	Member-at-Large
Dana E. Kepner (for L. C. Osborn)	Rocky Mountain Sewage Works Association
A. P. Miller (for E. C. Sullivan)	Federal Sewage Research Association
H. E. Miller (for Herbert A. Olson and James R. Rumsey)	Michigan Sewage Works Association
F. W. Mohlman (for H. W. Streeter)	Member-at-Large
Earle L. Waterman (for A. H. Wieters)	Iowa Wastes Disposal Association

The following were represented by proxy:

Name	*Representing*
Tom G. Banks (Proxy to H. E. Moses)	Oklahoma Water and Sewage Conference
Earnest Boyce (Proxy to H. E. Moses)	Kansas Water and Sewage Works Association
Austin Burt (Proxy to H. E. Moses)	California Sewage Works Association
V. M. Ehlers (Proxy to H. E. Moses)	Sewage Division, Texas Section, S.W.W.A.
Norman J. Howard (Proxy to H. E. Moses)	The Canadian Inst. on Sewage and Sanitation
W. Scott Johnson (Proxy to H. E. Moses)	Missouri Water and Sewerage Conference
W. S. Mahlie (Proxy to H. E. Moses)	Sewage Division, Texas Section, S.W.W.A.
Earle B. Phelps (Proxy to C. A. Emerson, Jr.)	Member-at-Large
D. H. Rupp (Proxy to H. E. Moses)	Kansas Water and Sewage Works Association
W. W. Towne (Proxy to H. E. Moses)	Dakota Water and Sewage Works Conference

Reading of the Minutes of the last Annual Meeting held January 22, 1937, was dispensed with, they having been printed in SEWAGE WORKS JOURNAL and there being no corrections.

REPORTS OF OFFICERS AND COMMITTEES

The Secretary-Treasurer, in his report, referred briefly to the beginning of the Federation, which was founded in 1928 with seven affiliated associations having an aggregate membership of 411. Only two of those were in the eastern section of the country, namely, Maryland and Pennsylvania. Since then the growth has been continuous, until now there are 25 affiliates with a gross membership of 2,358, an increase of over 1,900 members in the nine-year period covered. Affiliates are organized in 30 out of the 48 states. We have also a group in Canada, two in England and one in Argentina. There was a membership increase during the year of 256. The Secretary-Treasurer also reported the receipt and forwarding to the Business Manager of dues amounting to $3,098.50. Comment was made on the revision of the Constitution and By-Laws approved at the Board meeting January 22, 1937, the most radical change in which was an increase of membership dues by 50 per cent. Reference was made also to the preparation for the publication of a special volume marking the Federation's Tenth Anniversary, plans for which were well in hand at the end of the year.

The Business Manager made a report which was highly gratifying to the Board, indicating that the year 1937 produced a profit instead of a deficit as has been the case for several years past. This deficit previously has been met by contributions from The Chemical Foundation, all of which totaled, since 1928, the sum of $6,466.91. The operating statement for the year showed receipts of $11,613.43. The prin-

cipal disbursement was for cost of JOURNAL amounting to $9,719.92, or a profit on the JOURNAL of $1,893.51. This gross profit was reduced by other miscellaneous expenses to a net profit for the year of $1,633.13. The advertising income increased $732.47 over that of 1936. The total number of subscribers is 2,681, of which 380 are non-members. The cost of printing and mailing the JOURNAL for the year 1937 amounted to $2.94 per subscriber. It is worthy of comment that the Business Manager's report for 1936 showed a corresponding cost of $4.47. This report was gratifying to the Board members and reflected the careful and painstaking management of this part of the Federation's activities. The appreciation of the Board was expressed in a vote of commendation, referred to later in these Minutes.

Doctor F. W. Mohlman, Editor, reported briefly concerning SEWAGE WORKS JOURNAL, mentioning that most of the affiliates held their meetings in the Spring and Fall, resulting in an unusual quantity of material at those times. He referred to the section of the JOURNAL edited by Doctor Hatfield—Operators' Reports and Suggestions, inquiring as to its usefulness. A general discussion ensued, from which it was apparent that the articles published there have proven of distinct service and especially helpful to operators in general, but particularly to men operating the smaller plants.

Upon motion all of these reports were accepted.

Neither the Membership Committee nor the Publication Committee had any report. There were no applications for affiliation.

Inquiry was made whether the present form of Reviews and Abstracts met the needs of the membership, and it seemed generally agreed that it did so.

Under the item of Reports of Special Committees, it was announced that that of the Research Committee would be published in the March issue of the JOURNAL. The report of the Financial Committee was covered in other reports, particularly that of the Business Manager.

Concerning revision of standard nomenclature for sewage and sewage treatment, a subject discussed at the last Board meeting, Frank Woodbury Jones reported that the committees representing American Public Health Association and the American Society of Civil Engineers, and the Federation, did not function actively during the past year. Chairman Emerson suggested that a draft be made as a working basis and requested Mr. Jones, as the Federation's representative, to follow up the matter.

Mr. Buffum inquired concerning the report of the committee, authorized at the last Board meeting, to consider the selection of a new Business Manager. No report was available, and Mr. Buffum was earnestly requested to continue for the present until arrangements could be made to carry on his work and to relieve him. The matter was left in that status, Mr. Buffum reiterating his desire to be relieved.

Langdon Pearse, Editor, Tenth Anniversary Volume, submitted a report stating that progress at this time is slow but apparently sure, as all are greatly interested. Thirty-three well known engineers and

sanitarians have consented to write papers; a few have already submitted them. The topics chosen cover a wide range of endeavor. The business end of the enterprise has been arranged, and everything points to the successful production of an outstanding volume to mark the Tenth Anniversary of the Federation occurring October, 1938.

New Business

Under the head of new business there was an extended discussion on the publication of an index of material included in Sewage Works Journal since 1928—Volumes 1 to 9 inclusive. Chairman Emerson explained that his office had reviewed every issue and had prepared over 5,000 cards listing all Articles, Operators' Reports and Suggestions, Editorials, Proceedings and Reviews and Abstracts. He presented a typed analysis which showed the various details, and included estimates of cost for printing and binding. Based on the experience of other organizations, it was his opinion the Federation would need 750 copies.

In the discussion of details, the subject was thoroughly canvassed, including the question of the value of such an index, the need for both titles and authors, the inclusion of Abstracts, either with or without authors, publication of the Index in the Tenth Anniversary Volume, cost estimates and other pertinent features.

Finally it was moved, seconded and carried that the Index should include Volumes 1 to 10, ending with the close of the year 1938.

It was further moved and seconded that the Publication Committee work with the Executive Committee to determine the advisability of bringing out the Index and report to the Board by next Fall. This was amended to read that the Executive Committee be given power to act. The motion passed as amended.

Subsequently it was moved and seconded that Titles and Authors of Abstracts be omitted from the Index. The motion carried.

Professor Fair suggested that there should be included in one issue of Sewage Works Journal a report of progress of foreign affiliates, as an annual article.

Election of Officers

The Board next proceeded to the election of officers and selection of committees for the ensuing year. Nominations were made separately for each office, members-at-large and the executive committee, committees selected and approved, resulting in the following selection:

Officers

Chairman, C. A. Emerson, Jr., New York
Vice-Chairman, Linn H. Enslow, New York
Secretary-Treasurer, H. E. Moses, Harrisburg, Pa.
Business Manager, Wm. W. Buffum, New York

Members-At-Large

Wm. W. Buffum, New York
Linn H. Enslow, New York
Charles G. Hyde, Berkeley, Cal.
Wm. J. Orchard, Newark, N. J.
H. W. Streeter, Cincinnati, Ohio

Executive Committee

C. A. Emerson, Jr., *Chairman*
Linn H. Enslow
H. E. Moses, *ex officio*
Wm. W. Buffum
Wm. J. Orchard

Constitutional Committees

Membership

H. W. Streeter, Federal, *Chairman*
A. E. Berry, Canada
F. Wellington Gilcreas, New England

Publication

A. P. Miller, Federal, *Chairman*
John H. Brooks, Jr., New England
Wm. W. DeBerard, Central States
F. W. Mohlman, *ex officio*
Earle L. Waterman, Iowa

Special Committees

Research

Willem Rudolfs, New Jersey, *Chairman*

Finance

Wm. M. Piatt, North Carolina, *Chairman*
C. A. Emerson, Jr., New York
Dana E. Kepner, Rocky Mountain
C. D. McGuire, Ohio
F. W. Mohlman, Central States
Earle L. Waterman, Iowa

Joint Committee on Standard Nomenclature for Sewage and Sewage Treatment

Frank Woodbury Jones, Ohio

Tenth Anniversary

Langdon Pearse, Central States

It was moved, seconded and carried that the Board express its appreciation to Prof. Earle B. Phelps for his excellent work as Chairman of the Research Committee and for his valuable aid in furthering the interests of the Federation.

By motion, suitably made and passed, the Board, by rising vote, signified to Business Manager Buffum and Editor Mohlman its highest appreciation of their untiring work in the publication of SEWAGE WORKS JOURNAL.

There being no further business, the meeting adjourned at 10:15 p.m.

Respectfully submitted,

H. E. MOSES,
Secretary-Treasurer

REPORT OF SECRETARY–TREASURER, FEDERATION OF SEWAGE WORKS ASSOCIATIONS, FOR THE YEAR ENDING DECEMBER 31, 1937

As the Federation of Sewage Works Associations, beginning officially at Chicago, October 16, 1928, enters its Tenth year of existence, one is tempted to briefly review its history. The report of the Secretary-Treasurer made January 18, 1929, began with this statement:

> During the year 1928, as the outgrowth of the preliminary work carried on by a Committee of One Hundred, representing every section of the country, and later by four smaller committees working under a general chairman, the Federation of Sewage Works Associations was formed, and the publication of the SEWAGE WORKS JOURNAL was begun. The first issue appeared October, 1928.

At that time there were only seven affiliate associations having an aggregate membership of 411. Only one group had more than 100 members. The groups were:

Name of Association	*Number of Members*
Arizona Sewage Works Association	15
California Sewage Works Association	120
Central States Sewage Works Association:	
Illinois	
Wisconsin	
Indiana	62
Iowa Wastes Disposal Association	57
Maryland Water and Sewerage Association	44
Pennsylvania Sewage Works Association	85
Texas Sewage Works Association	28
	411

Significantly, the list included only two Eastern associations, viz.: Maryland and Pennsylvania.

During 1929 six more groups were admitted, raising the total to 13 with 1097 members. The following year two more were added, the membership increasing to 1243. None joined in 1931, but in 1932 three

new ones were approved, including the two English groups. In 1933 the Canadian unit affiliated, while by the end of 1935 the total number of affiliates had increased to 21 with a membership of 1667. The year following, 1936, four more were admitted, including the Argentine group, advancing the total to 25 with 2030 members. This past year no new affiliates were admitted but the membership at the close of the year reached the gratifying total of 2327, an increase of 1916 members in the nine-year period covered.

Affiliates are now organized in 30 of the 48 states, containing an aggregate population of nearly 95 million or 77 per cent of the entire population of the United States. Also there are a group in Canada, two in England and one in Argentina.

The gross membership of the 25 affiliates is 2373. Deducting 46 dual memberships, the net total is 2327, an increase of 271 during the year. The membership details appear in the analysis shown below:

	Gross Mem's'p	Dual Mems.	Gross New Mems. and Reinstatem'ts	Did not Renew Sub. 1937	Membership	
					Incr.	Decr.
Arizona S. Wks. Ass'n.	22	—	13	—	13	—
Cent. States S. Wkr. Ass'n.	347	3	143	26	117	—
California S. Wks. Ass'n.	235	2	52	41	11	—
Dakota W. & S. Wks. Conf.:						
North Dakota	26	—	26	—	26	—
South Dakota	22	—	18	—	18	—
Federal S. Research Ass'n.	61	—	14	5	9	—
Ga. W. W. & Sew. Opers. Ass'n.	20	—	9	8	1	—
Iowa Wastes Disp. Ass'n.	37	—	7	15	—	8
Kansas W. & S. Wks. Ass'n.	32	—	10	18	—	8
Md.-Del. W. & S. Ass'n.	26	—	3	8	—	5
Michigan S. Wks. Ass'n.	101	1	29	17	12	—
Missouri W. & S. Conf.	37	—	12	65	—	53
New England S. Wks. Ass'n.	146	7	16	18	—	2
New Jersey Sew. Conf. Group	58	—	9	8	1	—
N. Y. State S. Wks. Ass'n.	464	21	102	64	38	—
N. Carolina S. Wks. Ass'n.	86	1	33	5	28	—
Ohio S. Wks. Conf. Group	100	—	13	12	1	—
Oklahoma W. & S. Conf.	1	—	—	—	—	—
Pacific N. W. S. Wks. Ass'n.	37	—	14	13	1	—
Pennsylvania S. Wks. Ass'n.	177	9	34	25	9	—
Rocky Mt. Sew. Wks. Ass'n.	28	—	21	—	21	—
San. Engr. Div. of the Arg. Society of Engrs.	24	—	1	10	—	9
Sew. Div.-Tx. Sec. S. W. W. A.	40	—	29	—	29	—
The Can. Inst. on Sew. & San.	82	2	18	4	14	—
The Inst. of Sew. Purif.—Eng.	105	—	22	15	7	—
The Inst'n of San. Engrs.—Eng.	59	—	5	5	—	—
	2373	46	653	382	356	85
	46				85	
	2327 Net Mem's'p				271 Gr. Incr.	

Annual dues of members received by the Secretary-Treasurer and forwarded to the Business Manager amounted to $3098.50. The distribution as to affiliates is shown in the following table. The petty cash account of the Secretary-Treasurer for stamps and miscellaneous office expenses amounted to $13.25.

	For 1936	For 1937	For 1938	Total	Refund
Arizona S. Wks. Ass'n.	(Paid dues direct to Mr. Buffum)				
California S. Wks. Ass'n.	$1.00	$354.00	$	$355.00	$6.00
Cent. States S. Wks. Ass'n.	2.00	505.75		507.75	8.50
Dakota W. & S. Wks. Ass'n.	4.00	72.00		76.00	
Federal S. Research Ass'n.		91.50		91.50	
Ga. W. W. & Sew. Opers. Ass'n.		25.50		25.50	
Iowa Wastes Disp. Ass'n.		55.50	1.50	57.00	
Kansas W. & S. Wks. Ass'n.		49.50		49.50	
Md.-Del. W. & S. Ass'n.		39.00		39.00	
Michigan S. Wks. Ass'n.		148.50		148.50	1.50
Missouri W. & S. Conf.	(Paid dues direct to Mr. Buffum)				
New England S. Wks. Ass'n.	1.00	209.00		210.00	3.00
New Jersey Sew. Conf. Gr.		85.50		85.50	
N. Y. State S. Wks. Ass'n.	2.00	666.75		668.75	13.50
N. Carolina S. Wks. Ass'n.		129.00		129.00	1.50
Ohio S. Wks. Conf. Gr.		150.25		150.25	.25
Oklahoma W. & S. Conf.		1.50		1.50	
Pacific N. W. S. Wks. Ass'n.	(Paid dues direct to Mr. Buffum)				
Pennsylvania S. Wks. Ass'n.		250.50		250.50	4.50
Rocky Mt. Sew. Wks. Ass'n.		30.50	7.50	38.00	
San. Engr. Div. of the Arg. Society of Engrs.		40.25		40.25	5.75
Sew. Div.-Tex. Sec. S. W. W. A.	1.50	57.00	1.50	60.00	
The Can. Inst. on Sew. & San.		115.00		115.00	7.00
The Inst. of Sew. Purif.—Eng.	(Paid dues direct to Mr. Buffum)				
The Inst'n of San. Engrs.—Eng.	(Paid dues direct to Mr. Buffum)				
	$11.50	$3076.50	$10.50	$3098.50	$51.50

A matter worthy of mention was the revision of the Constitution and By-Laws approved at the Board meeting of January 22, 1937, and put into effect this past year. The original document, as revised, was adopted October 16, 1928, remaining in that form until 1937, serving quite well the needs of the Federation all these years. Relatively few major changes were made in the last revision, the most important being a fifty per cent increase of dues of members.

During the year plans have gone forward for the preparation and publication of a special volume marking the Federation's Tenth Anniversary. This volume as planned is expected to be a notable contribution in the field of sewage disposal and to rival the excellence of SEWAGE WORKS JOURNAL which continues to hold the preeminent place it has attained.

On October 8, 1937, a joint session was held in New York of the Engineering Section, American Public Health Association, the Conference of State Sanitary Engineers, and the Federation of Sewage Works Associations. This took the form of a symposium on Industrial Wastes. Papers and discussions were by men outstanding in this branch of the art. Subsequently these were published in SEWAGE WORKS JOURNAL, making a valuable contribution in this growing field.

H. E. MOSES,
Secretary-Treasurer

Reviews and Abstracts

H. W. Streeter

VENTILATION OF PERCOLATION FILTERS

By E. J. Hamlin and H. Wilson

The Surveyor, **92**, 800 (1937)

To obtain information upon which to design a partial treatment process preliminary to irrigation on land, an experimental plant was constructed and operated at Johannesburg. The object of the study was to determine the comparative efficiency of the Prüss enclosed filter and the open type percolating filter working under identical conditions. Another object was to determine the efficiency of a vertical-flow type of sedimentation tank with the sewage encountered, and the quantity of tank effluent a filter bed of given dimensions could purify.

The experimental plant consisted of a screening chamber, sedimentation tank, a dosing tank, an open filter, 40 ft. in diameter and 5 ft. 6 in. deep, and a Prüss enclosed filter with an internal diameter of 40 feet. The enclosed filter had Hume concrete semi-cylindrical aerating tiles spaced evenly on the circumference of the floor protruding through the footing of the wall. These tiles extend radially to the center of the filter and are covered with a layer of 3 to 6 in. stone, 18 in. deep. A 12-ft. layer of 1½-in. media follows and finally an 18-in. layer of 2- to 3-in. material.

The sprinkler is of the Ames-Crosta type. Air is forced into the top of the filter by means of a fan and is discharged uniformly through the tiles at the base of the filter wall. The filter material, aeration tile floor and distributors are as far as possible identical in the open and enclosed filter.

The sewage contains abattoir, gas liquor, brewery yeast, factory and various other industrial wastes, as well as night soil from large unsewered areas. The main outfall sewer is 9 miles long. Although bleaching powder is used, the sewage on arrival at the outfall is septic and highly objectionable.

The filters were dosed at high rates for a few hours each day for the first two weeks. The flow to the open filter was kept at 30 to 40 gal. per cu. yd. for the first month and was then slowly increased to 50 to 60 gal. per cu. yd.

The enclosed filter was much less sensitive to cold winds, and in the coldest winter months was operated at 3 to 4 times the rate of the open filter. An effluent of 100 per cent stability was the object of treatment with both filters.

The cost of the enclosed filter was about 8 times that of the open one. This included the cost of the gas engine for operating the pump and fan. The Prüss filter contained 705 cu. yd. and the open filter 267 cu. yd. of filter material. On the basis of the available filter media, the Prüss filter cost about 3 times the open filter. Data on costs of treatment per m.g. were not discussed as the authors believed that the Prüss filter should be improved upon.

The authors believe that much more work is necessary before definite conclusions can be reached. Two new 100 ft. filters, one 6 ft. and the other 12 ft. deep, are to be constructed, and it is hoped to present more conclusive information at a later date.

Discussion.—W. E. Speight (Bolton) criticized the authors for not stating whether the enclosed filter was advantageous from the point of view of smell or fly nuisance, and not giving an opinion after 12 months' operation on the question of the economic advantage of the enclosed filter. He also suggested a plan of operation to obtain comparative performance data on the filters, and was surprised to see 100 per cent stability recorded with B.O.D. figures of 65.9 and 58.9 p.p.m.

W. D. Scouller (Huddersfield) stated that although the authors had given very complete operating data on their filters for 12 months they were asking others for a solution. He then reviewed his experiences with filters and compared some of his experiments with those of the authors. Mr. Scouller's tentative conclusions were as follows:

" (1) Strong settled sewages can be filtered at rates of 1,000 gal. per cu. yd., and give a purification on the B.O.D. of 50 per cent of the settlement.
" (2) The upper surface of the filter must be kept warm in winter.
" (3) Artificial aeration is unnecessary."

S. Duxbury (Bedford) noted that very little reference was made to the shape and character of the filter medium, and suggested that it should be exceedingly hard and of irregular shape. He also brought up and discussed the question of bacterial environment in filters.

P. G. Lloyd (Kingston-on-Thames) suggested that as the paper left one guessing as to the authors' views on the enclosed filter, perhaps the authors held the same view that has been expressed many times, viz. that there was not so much in this type of filter as the patentees claimed for it.

F. E. Temple (Sanitary Engineer) questioned the justification of the cost of the enclosed filter and believed that all of the results claimed from it could be obtained by putting a light cover on the filter to keep the sun off and help stabilize the temperature and giving a dose of chlorine to prevent the sewage from producing hydrogen sulfide quite so easily.

H. C. Whitehead (Birmingham) said it was highly probable that both types of filter would give better results if the sedimentation tank effluent was diluted with at least one volume of humus tank effluent before application to the filters, in the case of the particular sewage used for these experiments.

J. Griffin (London) stated that the rapid success and general adoption of the enclosed ventilated filters in South Africa was alone responsible for the decision to install the experimental filter described in the paper. The worst sewage in Johannesburg was selected for treatment and the filter was guaranteed, subject to no payment, to purify, to the same extent, eight times as much sewage as an open filter of the same diameter.

C. C. RUCHHOFT

THE ELIMINATION OF THE DETRITUS DUMP

BY C. B. TOWNEND

The Surveyor, 92, 735–737 (1937). Discussion, *The Surveyor*, 92, 803–804 (1937); 93, 7–8 (1938)

The problem of detritus removal resolves itself into the handling of the grit and screenings, as the third ingredient of detritus, namely sludge, will be removed in the sedimentation tank. As the modern grit chamber employs a higher rate of flow than the detritus tank, the deposit of coarser organic material in the chamber cannot be avoided unless the screens are placed upstream to the grit chamber. On the other hand, there is always a reduction in velocity as the sewage approaches the screens and some grit may be deposited above the screens. It is pointed out, however, that by proper design and sluicing arrangements this may be minimized.

Screening.—In modern practice where machine cleaning of the sedimentation tanks is employed, it is advisable to have the screens of not more than ¾-in. openings. This size opening prevents the passage of rags, etc., which may hinder the operation of the mechanical cleaners. It is also necessary where the centrifugal pump is used to handle the sludge. The two methods of disposal of screenings are by incineration and digestion. The use of the disintegrator plant, which reduces the screenings to ½-in. size, allows them to be passed to the digestion tank without any trouble.

At the Mogden plant screenings of ¾-in. opening are used. The screenings then are passed through a disintegrator. With the recent advent of "stellite" (used to build up the cutting edges of the disintegrator), better efficiency in disintegration of the screenings is obtained, together with longer life of the knife edges. It is estimated that about 500 cu. ft. per day of screenings are obtained and that one disintegrator will handle this amount in about nine hours of operation.

Grit Chambers.—Ideally, grit should be produced so that it may be used for road construction or land fill without giving off offensive odors. In order to produce this kind of a grit, it is possible:

1. To construct the grit chamber of such dimensions that a fine control of flow is not obtainable and consequently some organic material is deposited with the inorganic grit, the former being subsequently removed.
2. To construct the grit chamber in such a manner that a fine control of flow is obtained, whereby a reasonably clean grit is obtained.
3. A combination of (2) followed by treatment as in (1), if a very clean grit is required.

The Dorr detritor is an example of the first method. The Link-Belt type of installation, where the grit is washed under water before final discharge, is another example. In this type of grit removal it is essential that the plant be designed as an oversize and that the material obtained should be further treated. If the Venturi flume used to record the volume of flow is located immediately below the grit chamber, then the flume will control the level in the grit chamber corresponding with the particular volume being discharged. In a multiple unit system each chamber may be controlled by its own flume. Such a system may be divided into groups so that one flume will control each group. By using such a system in dry weather only the minimum number of chambers need to be operated and shallow depths are avoided at minimum flow. With the multiple unit system it is also possible to design a battery of grit chambers so that the maximum flow to the plant including storm waters may be handled.

The Mogden Plant.—The flow from several sewers is discharged into a common junction chamber, thus obtaining a large flow with a comparative shallow depth. It is necessary to provide for an ultimate maximum flow of 575 m.g.d. at a maximum depth of 9 ft. The plant was finally subdivided into 12 equal units with a parabolic width of 15 ft. each. The units are so arranged that they operate in pairs, each pair being controlled by one flume. The length of the chamber is 90 ft., giving a detention period of 1.5 minutes, which is sufficient to allow a particle to fall through a depth of 9 ft. at a velocity of 0.1 ft. per second, which represents a factor of safety over the figure of 0.15–0.20 ft. per second usually assumed. It is pointed out that the reason for selecting a parabolic shape is that the grit tends to concentrate more readily at the invert of the parabola where it can be removed more easily. At the invert of the parabola the walls should slope at least 45 degrees. However, the walls of the upper part may be straight, thus economizing in space and material. The grit is removed by dredge pumps, each dredging machine serving two grit chambers. From the grit chamber the grit, together with some sewage, is pumped to storage hoppers where the grit settles out and the sewage is returned to the grit chamber. When sufficient grit has accumulated in the hopper, it is washed with clean water and then pumped to the disposal ground. Some trouble is encountered by the settling out of tea leaves, potato peelings, etc., in the grit chamber. These substances are then removed by the dredger to the hoppers, thence back to the grit chambers, thus there may be some accumulation of such substances in the grit chambers. The grit produced at the Mogden plant after washing contains approximately 98 per cent of inorganic material. At first it is black in appearance but gradually changes to a golden color.

The cost of detritus handling is reduced considerably by using the grit chambers rather than the detritus tanks. One reason for this reduction in cost is that it is necessary to handle a smaller quantity of grit.

Discussion

Mr. W. H. Hillier (London County Council) pointed out that the detention period of 1.5 minutes with a depth of 9 ft. applied at Mogden but was not strictly applicable to all plants. He also raised the question as to whether the grit was evenly distributed over the whole section of flow, his contention being that grit tended to settle sooner than one would conclude from theoretical considerations. Mr. Hillier questioned the statement that it was necessary to handle a smaller quantity of grit by using the grit chamber than by the detritus tank. He contended that if less grit was handled, then the tank was not efficient. He also raised the question as to whether the washing of the grit removed only the organic material.

Mr. R. C. Gibbs (London) raised the question as to how much grit passed over into the sedimentation tank, since the grit-washing hoppers were provided with an upward velocity of 0.2 ft. per second, which would allow grit finer than 28 mesh to find its way to the sedimentation tank. He pointed out that the grit chambers at Mogden, with their area of 15,000 sq. ft., would allow the settlement of all grit which possessed a settling rate of 0.083 ft. per second, which corresponds to grit of 48 mesh. The channels then were unnecessarily large.

In reply Mr. Townend stated that a velocity of 1 ft. per second in the grit chamber was usually found to be sufficient. As to the final washing of the grit, he stated that the grit deposit in the grit chamber was very often 90 per cent or more inorganic material and could be deposited in most cases without offensive odors. The quantity of detritus handled was reduced materially, since at some plants as much as 120 cu. yds. per day were removed, compared to 5 cu. yds. at Mogden.

Mr. J. P. Todd (London) raised the objection to the design of the Mogden grit chamber that since the inlet and outlet ends of the chamber were narrower than the middle, there would be a tendency for the current to flow down the center of the chamber. On examination of the small-scale model of the Mogden grit chamber, a distinct current through the center was noticeable. Mr. Townend stated that this condition did not apply to the large-scale plant however. Mr. Todd also stated that the elimination of the detritus dump was not so important in the case of small disposal plants. For example, his plant had no difficulty in disposal of the detritus or screenings without offensive odor, obtained from a sewered population of 50,000. In calculating the flow over the weir or through a standing wave flume, the width of the weir or flume was an important matter. Therefore, he could not see why there should be any difference in accuracy if one had 6 flumes 2 ft. wide or 1 flume 12 ft. wide. If there was any difference, the latter should be more accurate since there were only 2 side surfaces whereas in the former case there were 12.

Mr. H. Aldred (Sale) raised the question of the cutting edges of the disintegrators becoming dulled. As the screenings were mostly of organic nature, there should be little wear. The wash water must then contain considerable grit and if the final effluent were used for this purpose it might eliminate the dulling of the cutting edges.

Mr. J. Slater (Chorley) stated that the purpose of having 6 flumes instead of one was that they could be cut out in time of low flows or all used in times of high flows, thus maintaining a constant level in the grit chamber.

Mr. E. McG. Weir (Burnley) stated that the average velocity in the channels was taken to be at 0.6 of the depth and so there was a variation in velocity above and below this point which nullified the careful construction of the Mogden grit chamber to conform to the parabolic formula.

W. A. Moore

GRIT CHAMBER MODEL TESTS FOR DETROIT, MICH., SEWAGE TREATMENT PROJECT

By George E. Hubbell

Proceedings, American Society of Civil Engineers, **63,** No. 10 (December 1937)

The paper outlines a departure in grit chamber design and describes a basis of experiment for such design.

For economy, it was desired to build a deep grit chamber. The maximum flow per grit chamber unit was to be 250 cu. ft. per sec. with an entering velocity of 4 ft. per second. Moreover, it was necessary to contrive outlet conditions so as to cause floating grease to pass through the grit chamber.

The grit chamber as developed is 150 ft. long, 16 ft. wide and has 16 ft. maximum water depth. It is preceded by bar grates with ¾-in. openings and is equipped with scraper mechanisms. The approach channel has a maximum water depth of 6 ft. and the outlet is controlled by a weir and downward opening gate which leads to a submerged outlet conduit. The structure is covered (plan and sections are shown in the paper).

On the design for reducing the velocity and for passing rather than retarding grease, reliance was had upon tests with a one-fifteenth scale model. Conclusions from these were as follows:

" (1) There were no dead areas in the grit chamber;
" (2) Flow followed the divergence angle of 2 on 5 in passing from the screen section 12 ft. wide to the grit chamber 16 ft. wide without creating back eddies;
" (3) Flow followed the bottom configuration in the approach to the rack, the slope being 2 ft. on 5.26 ft. (20 ft. long—Abst.);
" (4) Flow followed the bottom configuration from the rack to the grit chamber, the slope being 2 ft. on 3.77 ft. (5 ft. long—Abst.);
" (5) Coloring matter moved with an approximately vertical front in a remarkably uniform manner through the grit chamber (the first color flowed through in 74 per cent of the theoretical time of 25.6 seconds, the main body in about 90 per cent, and the last color in 130 per cent of the time); and
" (6) No unusual horizontal or vertical velocity was observed. Coloring matter placed on one side of the channel remained on that side throughout the length of flow."

Distribution of flow is attributed to the bar grates in which the angle of slope was of little apparent effect. Also, floating grease was drawn from the grit chamber into the submerged outlet conduit when the draw-off velocity was 5 ft. per second and when the conduit roof sloped 4 on 1.

For grit settling effects in deep chambers, recourse was had to field experiments at the Grand Rapids and the Dearborn plants. In the first of these, there was used a channel 60 ft. by 8 ft. by 6 ft. deep; in the second a channel 85 ft. by 2½ ft. by 2.8 ft. deep. Velocities averaged 0.9 ft. per second. The test procedure consisted in dropping sand into the current and determining the resulting distribution within the grit chamber. The paper gives detailed tabular data of these results and also derived curves to show " the relation between the percentage removal of sand of a given size, and the length of tank required to obtain this removal." Curves so obtained were extrapolated for longer grit chambers.

The original inquiry at Detroit related to the possibility of removing all grit of a size greater than 0.2 mm., but analyses of grit obtained from digested sludge indicated that the passage of even a substantial amount of 0.2 mm. grit is not objectionable from the standpoint of wear upon equipment.

From the field experiments there were derived the following relationships (condensed from paper) between the performances of 15 ft. and 6 ft. deep grit chambers of different lengths:

Grit Size, mm.	Detroit Grit %	Per Cent Removals in Grit Chambers at Normal Velocity of 0.9 f.p.s.					
		50 ft. Long		100 ft. Long		150 ft. Long	
		15 ft. Deep	6 ft. Deep	15 ft. Deep	6 ft. Deep	15 ft. Deep	6 ft. Deep
0.8 and larger	5.7	5.7	5.7	5.7	5.7	5.7	5.7
0.4 to 0.8	8.7	6.4	8.7	8.4	8.7	8.7	8.7
0.3 to 0.4	13.2	7.1	12.0	10.7	13.2	12.8	13.2
0.2 to 0.3	22.3	7.8	14.9	13.1	20.8	16.3	22.3
0.15 to 0.2	21.3	6.0	10.6	9.6	14.3	11.7	16.2
0.1 to 0.15	11.8	2.8	5.5	4.7	7.1	5.6	8.1
Smaller than 0.1	17.0	1.0	2.2	2.0	3.2	2.5	3.8
Totals	100.0	36.8	59.4	54.2	73.0	63.3	78.0

These comparisons are regarded by the author as pointing to an economical length of 100 ft. The 150 ft. grit chamber was chosen because of lack of precedent and for greater removals of grit.

The general conclusion of the paper is that "deep grit chambers proportioned so that uniform velocity conditions exist are more economical to construct and will perform with the same degree of efficiency as grit chambers of one-half the depth and length and twice the width."

FRANK C. TOLLES

STANDARD PRACTICE IN SEPARATE SLUDGE DIGESTION

DISCUSSION BY H. E. SCHLENZ

Proceedings, American Society of Civil Engineers, **63**, 1114 (June, 1937)

A Progress Report of the Sanitary Division Committee on Sludge Digestion appeared in *Proceedings, American Society of Civil Engineers,* **63**, 39 (January, 1937). It was abstracted in *This Journal,* **9**, 317 (March, 1937). The current abstract is that of a discussion of the original Report. The author is Vice-President and Sales Manager, Pacific Flush Tank Company.

The report is criticized as not up-to-date in certain particulars. The author offers comment and addition as follows:

(1) The lists of digestion tank installations in Report Tables 7 and 8 are incomplete. As brought down to 1937 for the U. S. installations have been made or are building in some 285 cities instead of the 56 which the report records or could have recorded as built prior to 1932. A corollary of this increase is that recent installations have added greatly to data upon digestion.

(2) Report Table 3 from 30 installations gives an average heat value for sewage gas at 730 b.t.u. per cu. ft. The author segregates U. S. and European works and likewise the higher heat values from Imhoff tank gas and concludes that 650 b.t.u. per cu. ft. is a fairer value for the U. S.

(3) The gas collection data of Report Table 4 are subject to similar segregation. Relying upon recent data, the author states that the gas yield will range from 0.7 to 1.0 cu. ft. per capita daily. In terms of solids, gas production is 9 to 12 (ave. 10) cu. ft. of gas per lb. of dry volatile solids added to the tank or 17 to 19 cu. ft. per lb. of volatile solids destroyed.

The author indicates that quantity of gas should be correlated with the volatile solids load per unit volume of tank per time period to give cu. ft. of gas per cu. ft. digestion capacity per time period.

(4) Important to the selection of operating temperature for digestion is the greater sensitiveness of digestion at 130 deg. F. compared with digestion at the usual 80–90 deg.

(5) In the Report, a separate digestion tank with floating cover is shown to have a conical bottom which slopes 1 on 2. In recent designs bottom slopes of 1 on 5 or 6 are common and 1 on 12 has been used successfully.

(6) Report Table 9 on Utilization of Gas is, in 1937, subject to enlargement. The author cites 32 additional installations where sewage gas is used for power. These range up to the 1200 H.P. installation for District of Columbia.

(7) Gas explosion hazards should be emphasized, including the need for flame traps or protective devices. It is desirable that the design eliminate opportunity for retention of gas in control rooms; a ground level instead of a tunnel entrance is advocated and is illustrated.

(8) In the Report, the determination of digestion tank capacity is based in part upon the time required for complete digestion—defined as the time needed to obtain 75 per cent reduction of volatile solids. The author states that the per cent volatile reduction necessary for digestion is a function of the volatiles in the raw sludge. From plant data he presents a curve to show the relationship. The curve runs as a straight line thus—

	Volatile in Raw Sludge	Reduction for Digestion
From	52%	30%
To	80%	90%

(Values read from curve—*Abst.*)

Certain plant data have shown it possible to load digestion tanks up to 5.6 lb. dry total solids (4.5 lb. dry volatile solids) per cu. ft. of tank per 30 days. This loading is equivalent to 5.36 cu. ft. of tank volume per lb. dry total solids (6.67 cu. ft. per lb. volatile) added per day.

(9) In contrast with the Report statement that the volatile solids added to the tank daily should not exceed "5 per cent for controlled (heated) tanks," the author offers a curve which shows that loadings for a short period may depart widely from average long time loadings, thus—

Period	Load, Total Solids, Lbs./c.f./Month	Period	Load, Total Solids, Lbs./c.f./Month
11 days	16.0	20 days	5.8
5 days	8.8	25 days	5.5
10 days	6.9	30 days	5.15
15 days	6.1	50 days	5.05

Average for 8 months about 4.2 lbs./c.f./mo.
(Values read from curve—*Abst.*)

(10) In placing digestion tanks into operation, heating to optimum temperature accelerates starting and eliminates overloading and foaming. Initial heating is generally easier and more economical than the seeding which the Report suggests.

(11) The Report notes differences of opinion as to the value of stirring in digestion tanks, but considers only stirring. The author contends that digestion is a violent action and itself causes circulation of tank contents; in example he points out that stage digestion is a means for obtaining a better supernatant—a supernatant from the later

digestion periods which are less active with resulting reduced distribution of the solids. Stirring, in the author's view, may lead to withdrawal of some partially digested sludge.

(12) There is a trend toward subjecting supernatant liquor to supplementary settling, returning the solids to the digestion tanks and adding decanted liquor to the raw sewage.

(13) In the case of foaming the Report suggests, among other controls, liming or complete emptying of the tank. Foaming is an evidence of activity that follows upon overloading. In some cases liming but aggravates the condition; neither is a new start logical. Instead the author suggests (*a*) the lightening of additions to the tank, (*b*) frequent withdrawals of sludge in small amounts, and (*c*) keeping gas vents free.

FRANK C. TOLLES

AERATION TANKS FOR ACTIVATED SLUDGE PLANTS

BY S. W. FREESE

Proceedings, Am. Soc. C. E., **63**, 8 (1937)

The paper gives data relative to requirements of capacity, depth and width of tank and quantity of air as such are established by purification requirements and by economy in design.

Capacity.—Capacity in terms of daily average sewage flow involves the three factors of sewage quantity, sludge return and period of aeration and all three are related to the purification effect (including clarification) measured by the 5-day B.O.D. The curve of Aeration Period—Purification Effect varies with the per cent of sludge return, condition of sludge, kind of aeration, type and time of clarification and the temperature.

Aeration is separable into two stages. The first is a relatively short period (1 hour +) characterized by rapid coagulation and adsorption which are proportional to the amount of biologically active sludge that has been returned. In the second stage, purification is slower and is retarded by the oxygen demand of the returned sludge in the mixed liquor. Thus the optimum percentage of sludge return is that which results in the minimum time of aeration for the aggregate of both stages; but too low a return will render the mixed liquor inactive.

For complete treatment, the minimum aeration and the percentage of sludge return will depend upon the strength of the sewage. This the author shows by reference to the relationships for weak, strong and medium sewages, thus —

Data from	Aeration Time	Optimum Sludge Return	Solids in Return	Removals	
				5-day B.O.D.	Per Cent
Chicago—North Side	5.2 hrs.	21.7%	1.39%	104.5 p.p.m.	90.3
Milwaukee	6.3	32.5	1.19	257.0	95.2
Packingtown Experiments (Chicago)	9.0	60.0	0.85	720.0	96.0

These conclusions apply to complete treatment with no reaeration of sludge. Reaeration is required if normal aeration of mixed liquor is insufficient to maintain the biological activity of the sludge. Accordingly, reaeration is necessary when the treatment is partial rather than complete. Reaeration may be economical in complete treatment, but the author suggests that, unless experiment is directly available to prove this, it is preferable to design without reaeration, but to preserve enough flexibility in channels or in number of aeration tanks to permit of a later addition of reaeration if such proves desirable.

Depth of Tank.—A 15-ft. depth of aeration tank is almost universal in U. S. although some of the older British tanks were from 5 to 10 feet deep.

Experiments at Milwaukee and Chicago have showed little difference in air requirements for 10-ft. and 15-ft. tanks. Neither do the deeper tanks afford any greater oxygention effects from the diffused air. Apparently, surface tension of the air bubble and a colloidal coating serve to prevent transfer of oxygen until the bubble bursts at the surface. In confirmation of this the author cites his experiments, in which he concluded that nitrogen proved almost equally effective with air in the aeration process.

From these considerations it follows that the selection of tank depth will result from balancing the greater construction cost for shallow tanks against the greater power requirement for air diffusion in deeper tanks. The author regards 15 to 16 ft. as a probable economic limit of depth for average conditions.

Reference is made to the practice of placing diffuser tubes at mid-tank or other point in order to reduce power requirements; and attention is called to the need of imparting sufficient agitation to obtain mixing and to prevent deposition of solids.

Width of Tank.—Prevailing practice has been to maintain a ratio of tank width to tank depth at less than 1.5, but recent efforts have been directed to the possibility of widening the tank.

Experiments at Chicago led to a width (Southwest Plant) of 32.75 ft. (2.1 ratio) using 4 to 5 cu. ft. per min. of air per lineal foot of channel. At San Antonio, the center wall of one tank was omitted except for a low ridge. This has resulted in a tank 40.83 ft. wide (2.8 ratio) with three rows of diffuser plates along each wall, and in which the air diffusion is 8.5 cu. ft. per min. per lineal foot of channel. Chicago is experimenting (at Calumet) with a similar tank 68 ft. wide.

The author suggests that, for the present, the limiting ratio of width to depth should be about 2:1 for channels with diffuser plates along one wall.

Quantity of Air.—The air is required for mixing and also to maintain the sludge activity. For the latter purpose the amount needed is approximately ten times that needed to satisfy the B.O.D. of the sewage. For spiral flow and complete treatment the total air required amounts to 0.0038–0.0054 cu. ft. per gallon per part per million of 5-day B.O.D. removed in the over-all treatment process. This range might not obtain for a strong industrial sewage low in settleable solids. The requirement as stated appears to be independent of the aeration period, the sludge return, depth of tank, reaeration and also of preliminary treatment by settling or screening.

The fact that the inclusion or omission of pre-settling does not affect the need for air is attributed to the fact that the material removed has little B.O.D. and would be removed from the sewage in the final tanks. Pre-settlement has been advocated as yielding a denser sludge than is obtained in the final settling tanks, but question is raised as to whether the over-all concentration of all the sludge is so increased.

The author suggests that designs be based upon 0.005 cu. ft. of free air per p.p.m. B.O.D. removed in the over-all process, but that the blowers be in units to permit of reducing the air 20 per cent.

Spiral flow, although 25 per cent more economical of air than ridge and furrow diffusion, is but 60 to 70 per cent efficient. The use of mechanical agitation with diffusion of air may permit further economy. By combining methods in this way, Imhoff reports a reduction in power from 24 to 8.4 H.P. per M.G. and Mohlman and Wheeler at Chicago report a reduction from 26 to 13.1 H.P. per M.G.

General.—The layout should include enough independent batteries of aeration tanks to enable flexibility, but otherwise the number should be minimized. Longitudinal velocities should be such as not to entail large losses of head, and openings between channels should be large. Channels should be reserved to permit of reactivation. Deflector plates are desirable in the corners of the tanks.

Air diffuser plates are practicable within a range of 1 to 4 cu. ft. per min. per sq. ft. Within this range it is a matter of balancing plate cost against power cost. Bubble size is important but there is little difference in the bubbles obtained from 15 and from 60 permeability plates. At Chicago a 40 permeability plate gave air bubbles 0.0813 in. in diameter and containing 0.00028 cu. in.

The aim in designing air piping is to obtain uniformity of pressure throughout the aeration tank. Generally this will lead to oversized piping rather than to economical sizes for transmission service. Heat in the air should be conserved.

FRANK C. TOLLES

THE DETERMINATION OF OXYGEN IN WATER IN THE PRESENCE OF NITRITE

BY H. J. BRANDT

Gesundh.-Ing., **60**, 557–559 (1937). (Translation by W. A. Moore)

The Alsterberg azide method for the destruction of nitrites in the determination of O_2 in water has been approved for the routine checking of rivers. An occasional supposed failure is to be regarded as due to the premature titration of the sample, since it is shown that the time required for the destruction of nitrites by the azide is dependent upon the strength of the acidity of the reaction mixture and upon the dissociation constants of the kind of acids used. In the case of the highest possible acidity the sample must stand 10 min. after acidification before titration in order to assure complete destruction of the nitrites.

Although Ohle,[6] in a summary of methods of O_2 determination in water, says that the azide method of Alsterberg [2] for the prevention of errors due to nitrites in the Winkler determination of O_2 has no general practical importance, nevertheless the fact stands that it has been used continuously not only by us for a long time but also in other laboratories concerned with water investigation. When we add azide to the KI containing caustic liquor in accordance with the directions of Alsterberg, the later development of the interfering blue color upon titration is eliminated, so that the method has sufficed as the simplest for practical use in routine river investigation. Entirely unexpectedly the afterdevelopment of the blue color appeared again suddenly, *e.g.*, in the spring when the flood waters of the Bode, Salle, and Elbe were discharged, and a somewhat higher than usual nitrite content was present.

Alsterberg sets up the following equation for the destruction of the nitrite by means of Na azide, since the hydrazoic acid, in contrast to the urea suggested by Noll,[5] should react spontaneously:

$$N_2O_3 + 2\ HN_3 = 2\ N_2O + 2\ N_2 + H_2O$$

This is, however, only conditionally correct and depends to a very great extent upon the degree of acidity of the reaction mixture and the kind of acid used and its dissociation constant. According to Winkler's method, as is well known, the Mn hydroxide precipitate is brought into solution with sulphuric, hydrochloric, or phosphoric acids; in our laboratory HCl and in the presence of ferric ions, phosphoric acids were used.

In the following investigations the decomposition velocity of the nitrites by the azide will be carried out in solutions of different acidity and with the three acids. The degree of acidity was determined as a titration acidity against methyl orange and after dilution with tap water (pH 7.2) the pH determined by comparison. 100 c.c. or more of a $NaNO_2$ solution in tap water containing 6.5 mg./1. NO_2 was used corresponding to the capacity of the oxygen flask used (100–125 c.c.). Sodium azide solution: 2 g. to 100 c.c. H_2O.

Experiments.—(Nitrite determination with indol and the colorimeter according to Czensny.[3])

1. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 5 c.c. NCl—1.124 sp. gr. Acidity = 546 c.c. 1 *N* NaOH/1.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.0	6.50	1.5	0.05
0.5	1.00	2.0	0.02
1.0	0.25		

2. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 1 c.c. HCl

Acidity = 67 c.c. 1 *N* NaOH/1.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.0	6.50	2.0	0.40
0.5	1.00	2.5	0.25
1.0	1.00	3.5	0.12
1.5	0.70	7.0	0.00

3. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 3 c.c. H_2SO_4—1.84; diluted 1 to 3

Acidity = 268 *N* NaOH/1.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.0	6.5	1.5	0.25
0.5	1.0	2.5	0.07
1.0	0.5		

4. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 1 c.c. H_2SO_4—1 to 3

Acidity = 96 c.c. *N* NaOH/1.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.0	6.50	4.0	0.32
0.5	1.00	4.5	0.18
1.0	1.00	5.5	0.12
1.5	1.00	7.0	0.08
2.0	0.80	11.0	0.00
3.0	0.35		

5. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 1 c.c. H_3PO_4—1.12

Acidity = 18 c.c. *N* NaOH/1.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.0	6.5	20.0	0.50
0.5	1.0	25.0	0.40
3.5	1.0	30.0	0.25
7.0	1.0	32.0	0.05
10.5	0.9	35.0	0.02
15.0	0.7		

These experiments—especially Expts. 1, 2, 3, and 4—indicate that the destruction of the nitrites at first proceeds very rapidly to a certain value, then more slowly, and that the reaction velocity decreases with decreasing acidity of the solution; indeed the periods required for the decomposition are unexpectedly long. (Cf. Expts. 4 and 5.)

In the series of experiments 6 to 8, about the same acidity in the reaction mixture was maintained with the three different acids:

6. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 1 c.c. HCl

Acidity = 65 c.c. *N* NaOH/1. pH after diluting 1 : 100 with tap water = 6.42.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.0	6.50	2.5	0.45
0.5	1.90	3.0	0.22
1.0	1.40	3.5	0.15
1.5	0.88	4.0	0.15
2.0	0.65	7.0	0.01

7. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 0.75 c.c. H_2SO_4—1 to 3

Acidity = 63 c.c. *N* NaOH/1. pH after diluting 1 : 50 with tap water = 5.85; pH 1 : 100 = 6.42.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.00	6.50	5.0	0.60
0.25	1.75	5.5	0.60
1.00	1.60	6.0	0.41
2.00	1.28	6.5	0.38
2.50	0.96	7.0	0.30
3.00	0.88	7.5	0.30
3.50	0.84	9.0	0.03
4.50	0.70	11.0	0.00

8. 100 c.c. $NaNO_2$ soln. + 0.25 c.c. azide soln. + 3.1 c.c. H_3PO_4

Acidity = 64 c.c. *N* NaOH/1. pH after diluting 1 : 50 with tap water = 5.7; pH 1 : 100 = 6.1.

after....min.	mg./1. NO_2	after....min.	mg./1. NO_2
0.0	6.5	13.0	0.35
0.5	1.1	16.0	0.30
3.0	1.1	18.0	0.25
7.0	1.1	20.0	0.23
10.0	0.6	25.0	0.15
11.0	0.6	29.0	0.12

It is apparent that the most time is required for complete destruction of nitrites when acidification is with H_3PO_4; HCl is most efficient; H_2SO_4 intermediate.

About 5 c.c. of acid was added to the oxygen flasks (sample bottles) with a pipet in the usual manner or, according to another method of procedure, the space obtained by the removal of the glass stopper was completely filled with acid, which in the case of one type of our flasks amounted on the average to 4.7 c.c., with the other type only 3.7 c.c. According to Ohlmüller-Spitta,[7] 2 c.c. of HCl is sufficient for the solution of the Mn precipitate in the case of 100 and 125 c.c. flasks. In our case, however, it is found that a large portion of the acid is neutralized by the previously added c.c. of KI-containing caustic (36 per cent) and by the NaOH pellets (Merck, 0.2 g.) added when the sample is taken for the purpose of sterilization; the acidity is therefore considerably reduced.

The occasional further development of the blue color does not therefore indicate a failure of the azide method; but it appears rather when a sample accidentally of slight acidity is titrated immediately after acidification or in any case in too short a time thereafter, so that through the concurrence of these two conditions the nitrite is not completely destroyed. Thus a necessary requirement is to allow the samples to stand 10 min. after acidification, which has already been suggested by Haase[4] on other grounds. Moreover, care must be taken to ensure a sufficiently high acidity, even with the use of HCl; in the case of the small bottles 5 c.c. HCl is sufficient for the purpose if not more than one NaOH pellet is used for sterilization and if only 0.5 c.c. KI caustic is added, which according to Ohlmüller-Spitta has been found to be sufficient. The KI liquor must then contain twice the amount of azide. In the case of individual samples which, in the presence of ferric ions, are acidified with H_3PO_4, it is best to use the procedure of Haase and siphon off a portion of the water above the Mn precipitate in order to provide room for a somewhat larger amount of H_3PO_4. In the case of this method of dissolving the precipitate, certain technical precautions for the prevention of error are indispensable (Brandt[2]). We do not believe that an error, suspected in the case of the somewhat higher addition of acid according to Haase, as a result of the expulsion of a portion of the iodine by the warming of the liquid (chiefly when the flasks are again stoppered), is in any way essential in comparison with the necessity for a sufficient degree of acidity for the complete, rapid destruction of the nitrites. In the case of very high nitrite contents, as are encountered in the investigation of biological disposal

plants for city sewage or industrial wastes, the amount of azide used and the period of standing naturally must be increased.

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Childs, G. G., Box 801, Douglas, Ariz.
Cushing, Robert, 319 Homebuilders Bldg., Phoenix, Ariz.
Duff, Larry, City Hall, Prescott, Ariz.
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Ladlow, John W., P.O. Box 1784, Phoenix, Ariz.
McKeehan, Noel P., Room 9, Court House, Phoenix, Ariz.
McMorrow, Bernard J., Room 9, Court House, Phoenix, Ariz.
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Roberts, F. C., Jr., State Sanitary Engineer, State Board of Health, State Bldg., Annex, Phoenix, Ariz.
Travaini, Dario, 3rd Fl., City Hall, Phoenix, Ariz.
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Banta, A. Perry, Engineer, 110 S. B'way, 4th Floor, Los Angeles, Calif.
Barnard, Archer E., 601 W. 5th St., Suite 905, Los Angeles, Calif.
Barr, H. R., Route No. 1, Box 302, Redondo Beach, Calif.
Bates, John S., Consulting Engineer, 3134 Eton Ave., Berkeley, Calif.
Batty, Frederic A., 745 City Hall, Los Angeles, Calif.
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Pacific Foundry Company, 3100 19th St., San Francisco, Calif.

Palmer, Harold K., 110 S. Broadway, 4th Floor, Los Angeles, Calif.

Pardee, B., City Mgr., City Hall, Monterey, Calif.

Parkes, G. A., Asst. Engr., 1924 Leman Ave., So. Pasadena, Calif.

Parsons, F. W., Asst. Engr., City Hall, Los Angeles, Calif.

Patterson, R. L., City Engr., City Hall, Newport Beach, Calif.

Payton, Lyle, City Hall, Stockton, Calif.

Phelps, B. D., Civil Engineer, City Hall, 5th and G Sts., San Diego, Calif.

Phelps, Tracy I., Engineer, Los Angeles Co. Surveyor's Office, 400 Klinker Bldg., 307 W. 1st St., Los Angeles, Calif.

Pierce, C. L., Dist. Rep., Great Western Electro Chem. Co., 1925 Euclid Ave., San Marino, Calif.

Pleasanton, Town of, Town Hall, Pleasanton, Calif.

Polich, Theodore P., Pres. United Concrete Pipe Co., Box 1, Station H, Los Angeles, Calif.

Pomeroy, Richard, Chemist, L. A. County Sanitation Dists., 25421 President St., Harbor City, Calif.

Popp, W. L., City Engineer, City Hall, San Jose, Calif.

Porter, H., City Hall, San Mateo, Calif.

Post, Fred W., Sewage Plant Mgr., Rt. 3, Box 433, Lodi, Calif.

Ramseier, Roy. E., 619 Curtis St., Berkeley, Calif.

Ranagan, Fred E., 823 W. 5th St., Pardee Engineering Co., Los Angeles, Calif.

Rantsma, W. F., City Hall, Fresno, Calif.

Rawn, A. M., Los Angeles County Sanitation Dists., 110 S. B'way, 4th Floor, Los Angeles, Calif.

Reed, Chas. A., 7th Floor, City Hall, Oakland, Calif.

Reed, George W., National Park Service, Mineral, Calif.

Reinke, Edward A., State Dept. of Public Health, 3093 Life Sciences Bldg., Berkeley, Calif.

Reynolds, Leon B., Prof., Civil Engineering Dept., Stanford University, Calif.

Ribal, Raymond Rob., 701 City Hall, Oakland, Calif.

Roberts, W. C., 543 Call Bldg., San Francisco, Calif.

Robinson, Willis S., 152 East Louise St., Long Beach, Calif.

Robles, George G., Operator, 604 N. Church St., Lodi, Calif.

Sanchis, Jos. M., Sanitary Engr., 2341 Hillcrest Drive, Los Angeles, Calif.

San Diego, City of, City Hall, San Diego, Calif.

Sauer, Victor W., 701 City Hall, Oakland, Calif.

Schapp, A., Atty., 501 Hobart Bldg., San Francisco, Calif.

Schuch, H. W., City Hall, Burlingame, Calif.

Segel, A., Civil Engineer, 1221 Mattei Bldg., Fresno, Calif.

Senseman, Wm. B., 406 S. Main St., Los Angeles, Calif.
Shaw, Paul R., c/o Fish and Game Ferry Bldg., San Francisco, Calif.
Shearer, A. B., San. Dist. No. 1 Marin, 112 Tunystead Ave., San Anselmo, Calif.
Sherman, W. R., Box 102, Newman, Calif.
Shook, H. E., Great Western Electro-Chemical Co., 9 Main St., San Francisco, Calif.
Singer, Lewis P., Lincoln, Calif.
Skinner, John F., Consulting Sanitary Engineer, 3333 West 4th St., Los Angeles, Calif.
Skinner, W. V., Sewage Disposal Plant Opr., Box 22, Escondido, Calif.
Slane, Norman F., 4425 Mont Eagle Place, Los Angeles, Calif.
Smith, Alva J., 810 Boylston St., Pasadena, Calif.
Smith, C. A., Cons. Engineer, 300 Carmen's Bldg., 107 West Linwood Blvd., Kansas City, Mo.
Smith, H. G., Eng. of Sewer Design, City of Los Angeles, 745 City Hall, Los Angeles, Calif.
Smith, J. F., Great Western Electro-Chemical Co., 9 Main St., San Francisco, Calif.
Stevenson, Ralph A., 641 Gibbons St., Los Angeles, Calif.
Stites, H. I., City Engineer, 272 N. Olive Ave., Burbank, Calif.
Strayer, Elmer C., Civil Engineer, 204 S. Olive Ave., Alhambra, Calif.
Stuart, Archer B., City Engineer, P.O. Box 21, Healdsburg, Calif.
Studley, E. G., 705 City Hall, Los Angeles, Calif.
Sturgeon, Marvin, Engr. Oil Field Const. Co., Box 947, Bakersfield, Calif.
Sturgess, K. B., Sales Engr., Worthington Pump and Machinery Corp., 224 Townsend St., San Francisco, Calif.
Summers, William F., 10728 Westminster Ave., Los Angeles, Calif.
Taylor, Alva A., 2120 Cherry Ave., Signal Hill, Calif.
Tegtmeyer, L. G., Asst. Eng., 368 City Hall, San Francisco, Calif.
Tennant, Carl F., 216 Santa Fe Ave., Long Beach, Calif.
Thomas, Franklin, Prof. of Civil Engineering, Calif. Inst. of Tech., Pasadena, Calif.
Tremoureux, R. E., U. S. Lime Products Co., 1840 E. 25th St., Los Angeles, Calif.
University of California, Division of Serials and Exchanges, Berkeley, Calif.
University of Southern Calif. Library, University Park, Los Angeles, Calif.
Updegraff, W. R., Western City Magazine, 448 S. Hill St., Los Angeles, Calif.
Vance, Donald H., c/o Kellogg Supply Co., 110 S. Bowen St., Garden Grove, Calif.
Vaughan, E. A., K. of P. Bldg., Lompoc, Calif.
Waggoner, E. R., 306 West Ave., 26, Los Angeles, Calif.
Wakeman, C. M., 1413 N. Edgemont, Los Angeles, Calif.
Walters, Grover L., 123 W. Wilshire Ave., Fullerton, Calif.
Warren, A. K., 110 S. B'way, 4th Floor, Los Angeles, Calif.
Warrington, H. E., 110 S. B'way, 4th Floor, Los Angeles, Calif.
Watkins, H. H., Cleaves Bldg., Auckland, New Zealand.
Weed, Sam A., 3875 Ruby St., Oakland, Calif.
Weppener, C. J., 183 N. Rosanna St., Gilroy, Calif.
West, Ezra, 308 N. 10th St., Colton, Calif.
West, F. A., Engineer, 422 E. Jackson St., Stockton, Calif.
White, Russel C., National Park Service, Yosemite National Park, Calif.
Whitehead, Richard S., U. S. Coast and Geodetic Survey, 1009 Palm Ave., San Mateo, Calif.
Wilson, T. C., 4608 West Ave. 41, Los Angeles, Calif.
Wintersgill, A. T., Box 145, Station A, Los Angeles, Calif.
Woodward, R. D., 463 Laguna St., Laguna Beach, Calif.
Wyman, A. W., 419 S. Meredith Ave., Pasadena, Calif.
Young, John T., 826 Yale St., Los Angeles, Calif.
Zuckweiler, G. C., 739 4th St., San Diego, Calif.

Central States Sewage Works Association

Mr. W. H. Wisely, *Secretary-Treasurer*, State House, Springfield, Ill.

Abplanalp, C. C., c/o Wallace and Tiernan Co., 605 W. Washington, Chicago, Ill.
Activated Sludge, Inc., Johnston, C. W., Pres., 141 West Jackson Blvd., Chicago, Ill.
Adams, Chas. L., 202 Elks Bldg., Joliet, Ill.
Algonquin, Village of, McHenry County, Ill.
Alvord, Burdick and Howson, Suite 1401, Civic Opera Bldg., Chicago, Ill.
Anderson, L. E., Plant Opr., 309 Lyle St., Kewanee, Ill.

Anderson, Norval E., Civil Engr., San. Dist. of Chicago, 618 Catherine Ave., LaGrange, Ill.

Angell, Ben, 134 East Madison St., Tipton, Ind.

Arbogast, Joseph, Naperville, Ill.

Arnesen, H. P., Civil Engr., 1509 Pioneer Bldg., St. Paul, Minn.

Ashby, Paul, R.R. No. 6, Box 17, Muncie, Ind.

Ashley, Clifford A., 506 N. West St., Wheaton, Ill.

Babbitt, H. E., Sanitary Engr., 204 Engineering Hall, University of Illinois, Urbana, Ill.

Bachmann, Frank, Mgr., Sanitary Engineering Div., The Dorr Co., Inc., 221 N. LaSalle St., Chicago, Ill.

Baillie, E. P., 2700 Regent St., Madison, Wisc.

Baker, C. M., 2 So. Carroll St., Madison, Wisc.

Barnes, L. T., Supt., Wheaton Sanitary Dist., 825 Irving Ave., Wheaton, Ill.

Barnett, G. R., 519 Comm. Bank Bldg., Peoria, Ill.

Barnhill, John T., San. Chemist, 606 Blaine St., Peoria, Ill.

Barth, John R., Room 108, Decatur Club Bldg., Decatur, Ill.

Bass, Frederic, Civil Engr., University of Minnesota, Minneapolis, Minn.

Baylis, John R., 1643 East 86th St., Chicago, Ill.

Beatty, E. J., State Board of Health, Madison, Wisc.

Beaudoin, Robert E., San. Dist. of Chicago, Southwest Sewage Plant, Chicago, Ill.

Beck, A. J., 4914 Mulford St., Niles Center, Ill.

Becker, H. M., Supt. of Sewers, 406 4th St., Carmi, Ill.

Bender, Dwight O., 1110 N. Tuxedo St., Indianapolis, Ind.

Berry, George A., Route 2, Box 440, Indianapolis, Ind.

Bird, K. H., c/o Norton Company, Worcester, Mass.

Birkeness, O. T., Room 511, 605 W. Washington Ave., Chicago, Ill.

Black, Hayse H., Asst. Sanitary Engr., State Dept. of Public Health, Springfield, Ill.

Bloodgood, Donald E., R.F.D. 3, Box 976, H, Indianapolis, Ind.

Bohman, Joseph J., Supt. Sewage Treatment Plant, Fox River Grove, Ill.

Boley, Arthur L., Asst. City Engineer, City Hall, Sheboygan, Wisc.

Bosch, Herbert M., San. Engr., Minn. State Dept. of Health, Dept. of Sanitation, University Campus, Minneapolis, Minn.

Boston, Charles E., Supt. of Sewers, 112 Emily St., Mt. Morris, Ill.

Bradney, Leland, City Engineer's Office, Sioux Falls, South Dakota.

Brady, James, 417 Melrose Ave., Glen Ellyn, Ill.

Brensley, A. A., Supt. of Sewers, City Hall, Kankakee, Ill.

Brower, James, 3021 N. 36th St., Milwaukee, Wisc.

Brown, Floyd J., San. Engr., Marion Bldg., Marion, Ohio.

Brown, George L., City Hall, Austin, Minn.

Bruce, Frank P., Box 3598, St. Paul, Minn.

Burchby, Byron A., 437 W. Williams St., Decatur, Ill.

Burgeson, J. H., Operator, Sewage Treatment Plant, 301 Anderson Blvd., Geneva, Ill.

Burlingame, Hitchcock and Estabrook, Att: Mr. Joseph B. Estabrook, 521 Sexton Bldg., Minneapolis, Minn.

Burrin, Thomas J., Supt. of Water Works and Sewage, 111 E. Main St., Lebanon, Ind.

Bushee, Ralph J., 1647 King, Columbus, Ohio.

Caldwell, H. L., 803 W. College Ave., Jacksonville, Ill.

Calvert, C. K., 951 West 20th St., Indianapolis, Ind.

Campbell, M. S. A., Bacteriologist, Indiana State Div. of Public Health, Indianapolis, Ind.

Carey, Wm. N., Civil Engr., 432 Uptown P.O. Bldg., St. Paul, Minn.

Carpenter, Carl B., Supt. of Sewage Treatment Works, Bloomington, Ind.

Cash, T. T., Grinnell Co., Inc., 240 7th Ave., South Minneapolis, Minn.

Chadwick, E. E., City Engr., City Hall, Winona, Minn.

Chicago Pump Co., 3336 Wolfram St., Chicago, Ill.

Clark, E. S., Bacteriologist, Div. of San. Engineering, State Dept. of Public Health, Springfield, Ill.

Consoer, Arthur W., Consoer, Townsend and Quinlan, 205 W. Wacker Drive, Chicago, Ill.

Coon, J. H., General Chemical Co., 110 5th Ave., S.E., Minneapolis, Minn.

Cornilsen, C. K., Works Operator, Bloom Township, San. District, P.O. Box 1, Chicago Heights, Ill.

Corr, Ray H., Supt. of Sewers, Woodstock, Ill.

Corrington, C. E., Supt., Clinton Sanitary District, Clinton, Ill.

Cramer, Robert, 647 W. Virginia St., Milwaukee, Wisc.
Dailey, Lawrence T., 1659 Central Ave., Indianapolis, Ind.
Darling, Orin M., Cons. Civil Engr., 2615 West Drive, Fort Wayne, Ind.
Dawson, F. M., Dean of College of Engineering, State University of Iowa, Iowa City, Iowa.
DeBerard, W. W., Mgr., 520 N. Michigan Ave., Chicago, Ill.
DeBrun, John W., Resident Engineer, Taylorville, Ill.
Decker, Walter G., Supt. of Public Works, Laurenceburg, Ind.
Deckert, Christ, Sewage Treatment Works, Delavan, Wisc.
DeLeuw, C. E., 20 N. Wacker Drive, Chicago, Ill.
DeLong, R. E., Designing Engineer, Menasha, Wisc.
DePoy, A. G., 117 6th Ave., So., South St. Paul, Minn.
Deuchler, Walter E., 63 So. La Salle St., Aurora, Ill.
Dick, Robert, 267 Columbia Ave., Elmhurst, Ill.
Dietz, John, Plant Opr., Mundelein, Ill.
Dobbs, Melvin A., Asst. San. Engr. Dept. of Public Health, Springfield, Ill.
Domogalla, Bernhard, St. Lab. of Hygiene, Madison, Wisc.
Donohue, Jerry, P.O. Box 489, Sheboygan, Wisc.
Downer, Wm. J., Dept. of Public Health, Springfield, Ill.
Duvall, Arndt J., Box 3598, St. Paul, Minn.
Dworsky, Leonard, Ill. State Health Dept., Div. Sanitary Engr., Springfield, Ill.
Ebaugh, G. M., 415 Millikin Bldg., Decatur, Ill.
Erickson, Carl V., 312 W. Washington, Urbana, Ill.
Fadden, Glen L., c/o Crane Co., 400 3rd Ave., North Minneapolis, Minn.
Feltz, Fred C., Supt., Sewage Treatment Plant, Box 261, West McHenry, Ill.
Ferebee, James L., Box 1167, Milwaukee, Wisc.
Fischer, Math, 516 6th Ave. So., West Bend, Minn.
Fisher, L. L., Dept. of Sanitation, Frankfort, Ind.
Flickinger, Lloyd H., Civil San. Engr., 1923 University Ave., St. Paul, Minn.
Forsberg, Ole, c/o Oliver Iron Mining Co., Hibbing, Minn.
Frazier, R. W., City Hall, Oshkosh, Wisc.
Freason, Anthony, Operator, Grays Lake, Ill.
Freeland, B. H., Supt. of Utilities, Bluffton, Ind.
Friberg, H. H., 1725 Rockton Ave., Rockford, Ill.
Gail, A. L., North Shore San. District, 1015 St. Johns Ave., Highland Park, Ill.
Geiman, Edward, 419 Oakland Ave., Villa Park, Ill.
Gerard, F. A., 242 Columbia Ave., Park Ridge, Ill.
Geupel, Louis A., City Civil Eng. and Director of Public Works, 416 Washington Ave., Evansville, Ind.
Giesey, J. K., c/o Greeley and Hanson, Buffalo Sewer Authority, Buffalo, N. Y.
Gifford, J. B., Chemist, Sewage Disposal Plant, 124 Ashland Ave., Michigan City, Ind.
Gneagy, Harold, Operator, Sewage Treatment Works, 1709 Cypress St., Highland, Ill.
Goodman, Arnold H., 363 Downing Rd., Riverside, Ill.
Grabbe Construction Co., H. A., 500 Belle St., Alton, Ill.
Greek, Edward B., Operator, 26 East Fourth St., Hinsdale, Ill.
Greeley, Samuel A., 6 North Michigan Ave., Chicago, Ill.
Gross, Carl D., Engr., State Dept. of Health, Springfield, Ill.
Hager, Fred., Operator, 426 June Terrace, Barrington, Ill.
Hagestad, Herman T., Cons. Engr., River Falls, Wisc.
Hall, George, Engr., Sewage Treatment Plant, Janesville, Wisc.
Hammond, Edward E., Maintenance Operator, 32 Blackford Ave., Evansville, Ind.
Hansen, Paul, 6 North Michigan Ave., Chicago, Ill.
Hardman, Thomas T., 211 So. Center St., Terre Haute, Ind.
Harmeson, D. K., San. Engr., c/o Dr. C. A. Peterson, 518½ 15th St., Moline, Ill.
Harmon, Jacob A., Cons. Engr., 945 Jefferson Bldg., Peoria, Ill.
Harris, George C., Sewage Treatment Works, Arlington Heights, Ill.
Hartman, B. J., Engr., P.O. Box 489, Sheboygan, Wisc.
Hasfurther, Wm. A., c/o Dr. L. S. Barger, Golconda, Ill.
Haste, J. R., Asst. Plant Opr., 521 Green St., Rockford, Ill.
Hatfield, W. D., Decatur Sanitary District, Decatur, Ill.

Hathaway, A. S., Asst. Prof. in Engineering, College of Engineering, Northwestern University, Evanston, Ill.

Healy, Jr., Dennis L., Healy-Ruff Company, 765 Hampden Ave., St. Paul, Minn.

Hendricks, W. L., Opr., Sewage Treatment Works, Nashville, Ill.

Hendrix, George K., Div. of Sanitary Engr., State Dept. of Public Health, Springfield, Ill.

Henn, Donald E., DeKalb Sanitary District, DeKalb, Ill.

Henning, Bert, Operator, Sewage Treatment Plant, Effingham, Ill.

Henry, Murray H., 223 West Hubbard St., Chicago, Ill.

Herrick, T. L., 717 No. Washington St., Park Ridge, Ill.

Hodgin, S. W., City Civil Engr., City Bldg., Richmond, Ind.

Hofland, John, c/o Country Home for Crippled Children, R.F.D. No. 1, West Chicago, Ill.

Holderby, J. M., Neenah Menasha Sewerage Comm., Menasha, Wisc.

Holloway, Glenn, City Farm, Winchester, Ind.

Holmes, Frank, Sanitary Engr., Adams, Wisc.

Howe, J. M., c/o Cincinnati Rubber Mfg. Co., 808 LaSalle Ave., Minneapolis, Minn.

Hudson, LaVerne D., 323 E. 4th St., Flora, Ill.

Hull, S. P., Supt. of Utilities, City Bldg., Huntington, Ind.

Hume, Jr., John, 2001 Pershing Road, Chicago, Ill.

Hummel, Leslie C., Plant Opr., Fort Atkinson, Wisc.

Hunt, L. W., Supt. Galesburg Sanitary District, Galesburg, Ill.

Hurd, Charles H., 333 No. Pennsylvania St., Indianapolis, Ind.

Hurd, Edwin C., San. Engr., 344 Blue Ridge Rd., Indianapolis, Ind.

Hurwitz, Emanuel, 5017 Mozart St., Chicago, Ill.

Husted, Warren, Engr., 602 Insurance Exchange Bldg., St. Louis, Mo.

Indiana State Board of Health, Bureau of Sanitary Engineering, Att: B. A. Poole, Chief Engr., 201 State House Annex, Indianapolis, Ind.

International Filter Co., 59 E. Van Buren St., Chicago, Ill.

Jenson, Theodore B., 4541 43rd Ave., So., Minneapolis, Minn.

Jeup, Bernard H., 2415 No. Talbott, Indianapolis, Ind.

Johnson, Paul, 930 K. of P. Bldg., Indianapolis, Ind.

Jonas, Milton R., 5513 Cornell Ave., Chicago, Ill.

Jones, Howard H., Chief Opr. Sewage Treatment Works, 122 N. Calumet Ave., Michigan City, Ind.

Kallas, James G., 52nd Ave. and 39th St., Cicero, Ill.

Kalste, Arthur, Opr., Sewage Treatment Plant, Cedar Grove, Wisc.

Karpen, R. J., Asst. San. Engr. Minn. Dept. of Health, Division of Sanitation, Minneapolis, Minn.

Kashihara, F., Civil Engr., South Manchuria Railway Co., Sinking, Manchukuo, China.

Kempe, Lloyd L., Asst. San. Engr., Minn. State Dept. of Health, Dept. of Sanitation, University Campus, Minneapolis, Minn.

Kessler, Lewis H., C.E., Hydraulic and San. Engr., Hydraulic and San. Laboratory, University of Wiscinson, Madison, Wisc.

Kewer, J. F., P.O. Box 152, Waukesha, Wisc.

Kingsbury, Harold N., 801 6th Ave., W., Ashland, Wisc.

Kinney, E. F., 5414 Broadway, Indianapolis, Ind.

Kingston, Paul, State Health Dept., District No. 2, Court House, Mankato, Minn.

Kinsey, L. B., Civil Engineer, Pekin, Ill.

Kirchoffer, W. G., Vroman Block, Madison, Wisc.

Klassen, C. W., Act. Chief San. Engr., State Dept. of Public Health, Springfield, Ill.

Kleiser, Paul J., Asst. Sanitary Engr., 201 State House Annex, Indianapolis, Ind.

Knechtges, O., 1110 Vilas Ave., Madison, Wisc.

Koch, Philip L., 947 E. Johnson St., Madison, Wisc.

Koppers Company, Western Gas Division, Fort Wayne, Ind.

Kraus, L. S., Chemist, 215 N. Underhill St., Peoria, Ill.

Kuhl, F. A., Opr., Sewage Treatment Works, Breese, Ill.

Kutz, Chas. W., Brig. Gen. U. S. Army, Retired, 2032 Allen Place, Washington, D. C.

Lakeside Engineering Corp., 222 West Adams St., Chicago, Ill.

Lamb, Miles, Supt., 227 W. Marshall St., Belvidere, Ill.

Larsen, Stanley J., Mech. Engr., 1923 University Ave., St. Paul, Minn.

Larson, C. C., Springfield Sanitary Dist., Springfield, Ill.

Larson, Jarl E., Mech. Engr., 205 Uptown Sta., St. Paul, Minn.

Leland, Ben J., 130 S. Central St., Paris, Ill.
Lentfoehr, Charles E., Plant Opr., 322 N. Main St., Mayville, Wisc.
Leonard, O. M., 220 West LaSalle St., South Bend, Ind.
Lewis, R. K., 5009 Park Ave., Indianapolis, Ind.
Lindquist, T. G., Supt., Sanitary District of Rockford, 3300 Kishwaukee St., Rockford, Ill.
Linsley, Scott E., 1557 Holton Ave., St. Paul, Minn.
Long, H. Maynard, Hillsboro, Ill.
Lord, Herbert O., 308 Tenney Bldg., Madison, Wisc.
Lovett, F. W., 300 W. Pershing Road, Link Belt Co., Chicago, Ill.
Lustig, Joseph, City Engr., Janesville, Wisc.
Lutz, J. C., Livestock Exchange Bldg., South St. Paul, Minn.
McAulis, Chauncey R., City Engr., Dept. of Public Works, Ft. Wayne, Ind.
McClenahan, W. J., 910 S. Michigan Ave., Chicago, Ill.
McCormick, Edward S., 5653 Kenmore Ave., Chicago, Ill.
McCoy, M. H., 1541 Chicago Rd., Chicago Heights, Ill.
McIlvaine, Wm. D., Jr., Elec. Engr., Minn-St. Paul San. Dist., Box 3598, Childs Road, St. Paul, Minn.
McIntyre, John C., Sanitary Engr., Sewage Treatment Plant, Cedar Rapids, Iowa.
McKee, Frank J., 1818 Kendall Ave., Madison, Wisc.
MacKenzie, V. G., 16883 Monte Vista, Detroit, Mich.
Mackin, John C., Nine Springs Sewage Treatment Works, Madison, Wisc.
Marine, Earl, Opr., 225 Stout St., Menomonie, Wisc.
Martin, George C., 936 Kellogg St., Green Bay, Wisc.
Martin, S. C., San. Engr., State Dept. of Public Health, Springfield, Ill.
Merz, H. Spencer, 3207 W. Gate Parkway, Rockford, Ill.
Merz, R. C., Chain Belt Co., Sanitation Div., Milwaukee, Wisc.
Metz, Roy L., Opr., Sewage Treatment Works, Carthage, Ill.
Mick, K. L., 4215 Nicollet Avenue, Minneapolis, Minn.
Milinowski, Arthur S., Cons. Engr., 830 Globe Bldg., St. Paul, Minn.
Miller, A. J., c/o Chicago Pump Co., 2336 Wolfram St., Chicago, Ill.
Miller, David R., City Bldg., Kokomo, Ind.
Miller, Lester, Asst. Engr., Bureau of Sanitary Engineering, District No. 2, Bolte Bldg., Huntingburg, Ind.
Miller, Merle J., Goshen, Ind.
Milling, Martin A., 3257 MacPherson St., Indianapolis, Ind.
Minneapolis-St. Paul San. District, 1923 University Ave., St. Paul, Minn.
Mohlman, F. W. Dr., 910 S. Michigan Ave., Chicago, Ill.
Moore, R. B., 930 K. of P. Bldg., Indianapolis, Ind.
Morgan, Philip F., Chicago Pump Co., 2336 Wolfram St., Chicago, Ill.
Morrow, Geo. H., Engineering Dept., City of Kokomo, Kokomo, Ind.
Muegge, O. J., Asst. San. Engr., State Board of Health, Madison, Wisc.
National Aluminate Corp., 6216 West 66th Place, Chicago, Ill.
Neiman, W. T., Cons. Engr., Freeport, Ill.
Nelle, Richard S., State Dept. of Public Health, Springfield, Ill.
Nichols, M. Starr, State Laboratory of Hygiene, Madison, Wisc.
Nickel, Jack B., 201 State House Annex, Indianapolis, Ind.
Nordell, Carl H., Advance Engineering Corp., Board of Trade Bldg., Chicago, Ill.
Obma, Chester A., State Board of Health, Dist. No. 3, Fond Du Lac, Wisc.
O'Mara, Richard, Mech. Engr., c/o Western Precipitation Corp., 1016 West 9th St., Los Angeles, Calif.
Pacific Flush Tank Co., 4241 Ravenswood Ave., Chicago, Ill.
Palm, George, Plant Opr., Box M, LaGrange, Ill.
Palmer, John R., 1321 Monroe St., Evanston, Ill.
Palmer, Ralph M., Lincoln Hotel, Duluth, Minn.
Pearse, Langdon, Chicago Sanitary District, 910 So. Michigan Ave., Chicago, Ill.
Pecker, Joseph S., Mech. Engr., 1011 Chestnut St., Philadelphia, Pa.
Peeters, Stephan M., Opr., Sewage Treatment Works, Little Chute, Wisc.
Peirce, W. A., Racine Water Dept., City Hall, Racine, Wisc.
Peterson, Ivan C., 130 N. Wells St., Chicago, Ill.
Peterson, Myhren C., Dist. Public Health Engr., Box 308, Bemidji, Minn.
Peterson, R. W., 126th St., and Cottage Grove Ave., Chicago, Ill.

Pfeiler, L. F., 8210 Kimbark Ave., Jackson Park Sta., Chicago, Ill.

Pierce, George O., Asst. Prof. of Public Health Engr., University of Minnesota, Room 112, Millard Hall, Minneapolis, Minn.

Plant Operator, Sewage Treatment Works, Lincoln, Ill.

Poole, B. A., Engr., 6421 B'way, R. No. 16, Box 9–P, Indianapolis, Ind.

Powell, J. C., Opr., Sewage Treatment Works, Princeton, N. J.

Price, O. L., Indiana Reformatory, Pendleton, Ind.

Putnam, A. R., Hotel Baker, St. Charles, Ill.

Quimby, Frank, Water Department, City Hall, Racine, Wisc.

Racek, Jr., L., Sauk City, Wisc.

Ragsdale, Willis, Opr., Sewage Treatment Plant, 449 So. State St., Elgin, Ill.

Ralston, George E., 1207 W. Pleasant St., Freeport, Ill.

Rankin, R. S., Engr., The Dorr Co., Inc., 221 North LaSalle St., Chicago, Ill.

Rascher, Henry A. Opr., Sewage Treatment Plant, Manteno, Ill.

Raymond, Rex, c/o Chain Belt Co., 808 LaSalle Ave., Minneapolis, Minn.

Red Wing Sewer Pipe Corp., Red Wing, Minn.

Reeve, S. P., Engr., 4706 Broadway Blvd., Kansas City, Mo.

Rein, L. E., Pacific Flush Tank Co., 4241 E. Ravenswood Ave., Chicago, Ill.

Remsburg, W. N., Research Engr., American Well Works, Aurora, Ill.

Reybold, D. C., Engr., The Dorr Co., Inc., 221 North LaSalle St., Chicago, Ill.

Richards, P. W., R.R. No. 3 Box 976–H, Indianapolis, Ind.

Richetta, J. D., 201 State House Annex, Indianapolis, Ind.

Richmen, W. F., 111 East Sanborn St., Winona, Minn.

Richter, Paul O., Oliver United Filters, Inc., 221 N. LaSalle St., Chicago, Ill.

Robins, Maurice L., Asst. Chemist, Minneapolis-St. Paul San. District, 1853 Randolph St., St. Paul, Minn.

Roe, Frank C., Carborundum Co., Niagara Falls, N. Y.

Rogers, Harvey G., State Board of Health, University Campus, Minneapolis, Minn.

Rogers, W. H., Supt., Downers Grove Sanitary Dist., Downers Grove, Ill.

Roland, Robert J., East 7th St., Cannelton, Ind.

Romaine, Burr, 289 East 9th St., Fond du Lac, Wisc.

Roob, F. H., Mgr., Water and Light Dept., Columbus, Wisc.

Ross, W. E., Supt., Richmond Sewage Treatment Works, 435 S. 9, Richmond, Ind.

Ruf, H. W., San. Engr., Hydraulic Laboratories, University of Wisconsin, Madison, Wisc.

Russell, J. H., Supt., Public Utilities, Rochelle, Ill.

Sager, John C., San. Engr., Minneapolis-St. Paul San. District, Box 3598, St. Paul, Minn.

Sanders, M. D., Res. Chemist, Swift and Co., Chemical Laboratory, Union Stock Yards, Chicago, Ill.

Sargent, H. H., Supt., Sewage Treatment Works, 320 N. Locust St., Sycamore, Ill.

Schacht, F. E., Supt., Public Works, City Hall, West Chicago, Ill.

Schier, Lester C., 206 W. Saveland Ave., Milwaukee, Wisc.

Schildman, W. H., 922 Doolin Ave., Jacksonville, Ill.

Schlenz, H. E., Pacific Flush Tank Co., 4241 Ravenswood Ave., Chicago, Ill.

Schoenfeld, David M., Sales Engr., 1930 Bankers Bldg., Chicago, Ill.

Schriner, P. J., Chemist, 195 South Fraser, Kankakee, Ill.

Schroepfer, George J., Metropolitan Drainage Comm., 1923 University Ave., St. Paul, Minn.

Schwartz, Oswald, Street Comm. Cederburg, Wisc.

Schwob, Carl E., Dept. of Public Health, Springfield, Ill.

Senn, Charles L., City Hall, Rhinelander, Wisc.

Simplex Ejector and Aerator Corp., 2400 W. Madison St., Chicago, Ill.

Sleeger, Warren H., Asst. San. Engr., Minneapolis-St. Paul San. District, 1923 University Ave., St. Paul, Minn.

Smith, E. E., Elgin Sanitary District, Elgin, Ill.

Smith, J. Irwin, 15032 Vine St., Harvey, Ill.

Smith, R. Trumbull, Sales Engr., Wallace and Tiernan Co., 416 Flour Exchange Bldg., Minneapolis, Minn.

Spangler, Charles D., San. Engr., State Dept. of Public Health, Div. of Sanitary Engineering, Springfield, Ill.

Sperry, Walter A., Aurora Sanitary District, P.O. Box 231, Aurora, Ill.

Spiegel, Milton, 1731 Albion Ave., Chicago, Ill.

Spiess, Reinhold, Litchfield, Ill.

Steffen, A. J., San. Engr., District No. 2, Elkhorn, Wisc.

Steffes, Arnold M., 1387 Jefferson Ave., St. Paul, Minn.

Steindorf, R. T., Chain Belt Co., 1600 W. Bruce St., Milwaukee, Wisc.

Stemper, J. Alex., Opr. Sewage Treatment Works, Oconomowoc, Wisc.

Storey, Ben M., 1923 University Ave., St. Paul, Minn.

Sullivan, Fred O., Chemist, Danville Sanitary District, 116 No. Beard St., Danville, Ill.

Sund, Gutorm, Plant Opr., Altoona, Wisc.

Suter, Max, 405 West Elm St., Urbana, Ill.

Taft, George H., 1016 19th Ave., S.E., Minneapolis, Minn.

Teske, H. O., Princeton, Wisc.

Tholin, A. L., 103 N. Wisner, Jackson, Mich.

Thomas, Ariel A., c/o Dept. of Civil Engineering, University of Illinois, Urbana, Ill.

Thompson, Cecil, 248 So. 4th St., Beechgrove, Ind.

Todd, J. A., 103 West Oak St., Kewanee, Ill.

Troemper, A. Paul, San. Engr., Room 204, City Hall, Peoria, Ill.

Tupper, T. C., Monsanto Chemical Co., St. Louis, Mo.

Turpin, U. F., 8940 Lavergne Ave., Niles Center, Ill.

Vagtborg, H. A., 3300 Federal St., Chicago, Ill.

Van Praag, Alex., Jr., 415–418 Millikin Bldg., Decatur, Ill.

Velzy, Chas. R., 6 North Michigan Ave., Chicago, Ill.

Wahlstrom, Carl A., 419 North 23rd St., La-Crosse, Wisc.

Walbridge, Thornton, Supt., Sewage Treatment Works, Dahringer Rd., Waukegan, Ill.

Walker, Donald, 568 Fox St., Aurora, Ill.

Walker, Vernon L., State Dept. of Public Health, Div. San. Engineering, Springfield, Ill.

Walraven, W. B., Springfield Sanitary District, Springfield, Ill.

Walton, Graham, Instructor, Hydr. and Sanitary Engineering, University of Wisconsin, Madison, Wisc.

Ward, C. N., Meade, Ward and Hunt, State Journal Bldg., Madison, Wisc.

Ward, Oscar, 1519 Richfield St., Marshfield, Wisc.

Warrick, L. F., State Board of Health, Madison, Wisc.

Weart, James G., 811 South State St., Springfield, Ill.

Weber, Carl N., Box 224, West McHenry, Ill.

Weber, E. J., Plant Opr., Oconimowoc, Wisc.

Wells, E. Roy, Civil Engr., Court House, Geneva Ill.

Wells, W. W., 868 So. Park Ave., Springfield, Ill.

West, A. W., Asst. San. Engr., Wisc. State Board of Health, District Office No. 7, Rutledge Charity Bldg., Chippewa Falls, Wisc.

Weston, Roy F., Dept. Sanitary Engr., New York University, University Heights, New York, N. Y.

Wheeler, C. E., Jr., Calument Sewage Treatment Works, 125th St. and Cottage Grove Ave., Chicago, Ill.

Whitley, F. H., Jr., San. Engr., Dept. of Civil Engineering, So. Dakota State College, Brookings, S. D.

Whittaker, H. A., Director, Div. of Sanitation, Minneapolis Dept. of Health, University Campus, Minneapolis, Minn.

Whittemore, L. C., Engr., Chicago San. District, 910 S. Michigan Ave., Chicago, Ill.

Wilbur, C. C., 2450 Pleasant Ave., Minneapolis, Minn.

Wileman, C. S., Link Belt Co., 300 West 39th St., Chicago, Ill.

Wiley, Ralph B., 777 Russell St., W. Lafayette, Ind.

Williams, Clyde E., 520 S. East St., Plainfield, Ind.

Williams, Leon G., 573 Potomac Ave., Buffalo, N. Y.

Williams, William D., 522 S. 6th St., Stillwater, Minn.

Williford, W. E., Supt. of Sewers, 2223 W. Broadway, Mt. Vernon, Ill.

Wilson, Harry L., Project Engr., Minn.-St. Paul San. District, 413 Uptown Federal Bldg., St. Paul, Minn.

Wilson, John, 610 Torrey Bldg., Duluth, Minn.

Wise, Nelson E., c/o Indiana State Director Federal Public Works, Administration, Indianapolis, Ind.

Wisely, W. H., Asst. Sanitary Engineer, State Dept. of Health, Springfield, Ill.

Wittenborn, E. L., Div. Sanitary Engineering, State Dept. of Public Health, Springfield, Ill.

Wolfe, J. F., Supt. of Sewers, Carpentersville, Ill.

Woltman, J. J., Cons. Engr., 225 Unity Bldg., Bloomington, Ill.

Woodward, F. L., Public Health Engr., Bureau of Health, Public Safety Bldg., St. Paul, Minn.

Zack, S. I., San. Engr., c/o Filtration Equipment Corp., 10 East 40th St., New York, N. Y.

Zielske, Wm., Plant Opr., 351 West Maple St., Lombard, Ill.

Dakota Water and Sewage Works Conference

North Dakota Section

M. D. Hollis, *Secretary-Treasurer*, U. S. P. H. S., State Dept. of Health, Bismarck, N. D.

Battershill, J. W., 206 Chambers of Commerce, Winnipeg, Manitoba, Canada.

Borgford, Th. B., 120 Fort St., Winnipeg, Manitoba, Canada.

Boyd, Alfred, Prof., Prof. of Engineering, University of North Dakota, Grand Forks, N. D.

Chandler, Dean E. F., University Station, Grand Forks, N. D.

Clark, L. K., State Health Department, Bismarck, N. D.

Collins, W. W., Indian Agency, Ft. Yates, N. D.

Edmundson, G. B., City Auditor, Cooperstown, N. D.

Finch, R. M., Wallace and Tiernan Co., Minneapolis, Minn.

Gilbertson, W. E., Dist. Engr., Dist. Health Unit, City Hall, Valley City, N. D.

Haggart Construction Company, Fargo, N. D.

Hanson, H. G., State Dept. of Health, Bismarck, N. D.

Hollis, M. D., U. S. P. H. S. State Dept. of Health, Bismarck, N. D.

Lauster, K. C., 1309 Washtenaw, Ann Arbor, Mich.

Lindsten, H. C., 301 Hamilton Bldg., Winnipeg, Manitoba, Canada.

Lium, E. L., Consulting Engr., Grand Forks, N. D.

Pearson, E. J., City Bacteriologist, Minot, N. D.

Pinney, F. W., 741 2nd St., No., Fargo, N. D.

Prince, H. G., Sewage Plant, Jamestown, N. D.

Quam, Harley G., Sewer Supt., Lisbon, N. D.

Roach, W. H., Water Commissioner, Carrington, N. D.

Svenkeson, S. K., Supt. Street and Sewer, Minot, N. D.

Tarbell, W. P., City Engineer, Fargo, N. D.

Toman, G. J., State Health Dept., Bismarck, N. D.

Turner, J. H., City Engineer, Grand Forks, N. D.

Veigel, L. W., City Engineer, Dickinson, N. D.

Waterous, F. A., Waterous Company, St. Paul, Minn.

South Dakota Section

W. W. Towne, *Secretary-Treasurer*, Division of Sanitary Engineering, S. D. State Board of Health, Pierre, So. Dakota

Bonell, John, Dist. Sanitary Engineer, Philip, S. D.

Bradney, Leland, City Engineer's Office, City Hall, Sioux Falls, S. D.

Bragstead, R. E., City Engineer, City Hall, Sioux Falls, S. D.

Emberg, John W., City Engineer, Madison, S. D.

Endersby, A. J., City Engineer, DeSmet, S. D.

Griffin, Ralph J., Box 595, Pierre, S. D.

Hook, John, Water and Sewer Supt., Iroquois, S. D.

Mather, Edward K., Dakota Engineering Co., 309 Western Bldg., Mitchell, S. D.

Mathews, E. R., Chemist, Aberdeen, S. D.

Mitchell, Robert D., Pierce Hall, Harvard University, Cambridge, Mass.

Murschel, Jacob, Supt. Water and Sewage, Webster, S. D.

Payne, R. Heslop, Dr., Director, Hutchinson County Health Unit, Tripp, S. D.

Pierce, H. M., City Engineer, Huron, S. D.

Poston, R. F., Asst. State Sanitary Engr., Pierre, S. D.

Price, Charles R., Supt. Sewage Treatment Plant, Box 590, Rapid City, S. D.

Reed, Ralph, Asst. City Engineer, Watertown, S. D.

Scallin, J. C., City Engineer, Mitchell, S. D.

Schulz, E. H., Supt., Sewer and Water Dept., Box 235, Watertown, S. D.

Summerson, G. F., City Auditor, Carthage, S. D.

Towne, W. Waldo, Director, Div. of Sanitary Engineering, Capitol Annex, Pierre, S. D.

Volio, E., Sanitary Engr., Dept. of Sanitary Engineering, San Jose, Costa Rica.

Wiley, John S., Asst. State Sanitary Engineer, Pierre, S. D.

Federal Sewage Research Association

R. W. Kehr, *Secretary-Treasurer*, East Third and Kilgour St., Cincinnati, Ohio

Augusterfer, R. J., (U. S. Treasurer Procurement Div. Pub. Bldgs. Branch, Supervising Architect's Office), 154 "T" Street, N.E., Washington, D. C.

Berry, C. Radford, 1215 North Second St., Harrisburg, Penna.

Bibelhausen, L. A., U. S. Indian Service, Neopit, Wisc.

Brent, I. D., State Director, 17525 Wildemere Ave., Detroit, Mich.

Butterfield, C. T., U. S. Public Health Service, Third and Kilgour Sts., Cincinnati, Ohio.

Carlson, H. R., Sanitary Engineering Asst., U. S. Public Health Service, Room 210, Federal Office Bldg., San Francisco, Calif.

Carnahan, Charles T., P.O. Box 1226, Miami, Florida.

Catlett, G. F., State Board of Health, P.O. Box 210, Jacksonville, Fla.

Clarke, Roy S., 3045 Clinton Ave., N.E., Washington, D. C.

Collins, W. D., U. S. Geological Survey, Interior Building, Washington, D. C.

Crohurst, Harry R., U. S. Public Health Service, Third and Kilgour Sts., Cincinnati, Ohio.

Crutcher, F. B., 1910 Biltmore St., N.W., Washington, D. C.

Donovan, C. F., 10 Upland Road, Dedham, Mass.

Dopmeyer, A. L., Board of Health Bldg., Honolulu, Hawaii.

Fisher, Lawrence M., U. S. P. H. S. Room 1722, Navy Bldg., Constitution Ave., Washington, D. C.

Frank, Leslie C., U. S. Public Health Service, 19th and Constitution Ave., N.W., Washington, D. C.

Freeman, A. B., U. S. Public Health Service, c/o State Board of Health, Raleigh, N. C.

Fuchs, Abraham W., U. S. Public Health Service, 19th and Constitution Ave., N. W., Washington, D. C.

Gordon, J. B., Room 309, District Bldg., Washington, D. C.

Haley, Charles R., 283 Summer St., Somerville, Mass.

Hasle, Harold, Fort Belevoir, Va.

Herringer, E. J., U. S. Public Health Service, Room 304, 210 State St., New Orleans, La.

Hommon, H. B., The District Engineer, U. S. Public Health Service, Room 210, Federal Office Bldg., San Francisco, Calif.

Hopkins, Omar C., U. S. P. H. Lab. Room 210, Federal Office Bldg., San Francisco, Calif.

Hoskins, J. K., U. S. Public Health Service, Third and Kilgour Sts., Cincinnati, Ohio.

Kehr, Robert W., U. S. Public Health Service, Third and Kilgour Sts., Cincinnati, Ohio.

King, Kenneth K., Sr. Sanitary Engr. (Resettlement Administration), 207 Monroe St., Hyattsville, Maryland.

Kochtitzky, O. W., (Jr. Sanitary Engineer), Box 128, Norris, Tenn.

Lamoureux, V. B., E. 3d and Kilgour Sts., Cincinnati, Ohio.

LeVan, J. H., U. S. Public Health Service, Scioto River Invest., P.O. Box 87, Chillicothe, Ohio.

Linders, Edward, Project Engineer, Public Works Administration, 3165 Ludlow Road, Cleveland, Ohio.

Male, Leonard H., Sanitation Section, U. S. Public Health Service, 19th and Constitution Aves., Washington, D. C.

Matullo, S. E., 1435 Morse St., N.E., Washington, D. C.

McDonald, F. L., State Board of Health, Little Rock, Ark.

McNamee, Paul D., Sewage Treatment Plant, Blue Plains, D. C.

Miller, A. P., U. S. Public Health Service, Sub-Treasury Bldg., Wall, Pine and Nassau Sts., New York, N. Y.

Moore, W. A., Chemist, U. S. Public Health Service, E. Third and Kilgour Sts., Cincinnati, Ohio.

Moss, F. J., U. S. Public Health Service, 19th and Constitution Ave., N.W., Washington, D. C.

Nesheim, Arnold, 228 Terry Ave., Billings, Montana.

Old, H. N., U. S. P. H. S., Room 304, 210 State St., New Orleans, La.

Purdy, William C., E. Third and Kilgour Sts., Cincinnati, Ohio.

Roberts, William E., State Health Department, Austin, Texas.

Robertson, J. L., Jr., Apt. 109, 3945 Connecticut Ave., Washington, D. C.

Ruchhoft, C. C., (Principal Chemist, U. S. P. H. S.), 1814 Andina Ave., Cincinnati, Ohio.

Scott, Guy R., 706 Mt. Vernon Circle, Chattanooga, Tenn.

Shaw, Frank R., U. S. Public Health Service, New Post Office Bldg., Suite 816, Chicago, Ill.

Smith, Russell S., c/o U. S. Public Health Service, E. Third and Kilgour Sts., Cincinnati, Ohio.

Streeter, H. W., E. Third and Kilgour Sts., Cincinnati, Ohio.

Stromquist, W. G., 3421 Glendon Ave., Chattanooga, Tenn.

Sullivan, E. C., U. S. Public Health Service, Domestic Quarantine Div., 19th St. and Constitution Ave., Room 327, Washington, D. C.

Tarbett, R. E., U. S. Public Health Service, 19th and Constitution Ave., N.W., Washington, D. C.

Tate, Guy M., Jr., Tennessee Valley Authority, Wilson Dam, Ala.

Theriault, E. J., U. S. Public Health Service, 19th and Constitution Ave., N.W., Washington, D. C.

Thomas, John B., 1428 Clifton St., N.W., Washington, D. C.

Thrasher, R. H., 905 Irving St., N.E., Washington, D. C.

Trulson, A., 5214 W. Chicago, N.W., Detroit, Mich.

Tucker, Joseph, Associate Engineer, 4829 16th St., N.W., Washington, D. C.

Ward, Fay N., 1100 17th St., South, Arlington, Va.

Woodward, Richard L., Interstate Sanitary District No. 2, U. S. Public Health Service, Washington, D. C.

Wright, Charles T., U. S. Public Health Service, Room 1722, Navy Bldg., Washington, D. C.

Wuhrman, William, 244 Main St., Matawan, N. J.

Georgia Water Works and Sewage Operators' Association

Paul Weir, *Secretary-Treasurer*, Superintendent Filtration Atlanta Water Works, 1194 Hemphill Ave., Atlanta, Ga.

deJarnette, Jr., Lewis W., Sanitary Engineer, 866 Briarcliff Road, N.E., Atlanta, Ga.

deJarnette, N. M., Director Water Laboratory, State Board of Health, State Capitol, Atlanta, Ga.

DuPre, R. B., Gen. Mgr., Board Lights and Water, Marietta, Ga.

Eggert, E. G., State Board of Health, P.O. Box 666, Albany, Ga.

Frith, G. R., 1425 McPherson Ave., S.E., Atlanta, Ga.

Gray, Odell W., Chemist, Water Softening Plant, Thomasville, Ga.

Handley, L. W., Water Plant Operator, LaGrange, Ga.

Hansell, Wm. A., Asst. Chief Const. and Engr. of Sewers, City Hall, Atlanta, Ga.

Hoy, J. R., San. Engr., 408 Hildebrandt Bldg., Jacksonville, Fla.

Jacobs, L. L., Supt. Filtration, Newnan Water Works, Newnan, Ga.

Jones, T. A., Supt. Light and Water Dept., Fort Valley, Ga.

Kahn, J. M., 42 W. 25th St., Atlanta, Ga.

Lowe, Prof. Thomas M., Asst. Prof. of Civil Engineering, University of Florida, Gainesville, Fla.

McCamy, Roy L., San. Engr., P.O. Box 34, Marietta, Ga.

Simonton, Lewis, Filtration Supt., Griffin Water Works, Griffin, Ga.

Smalshaf, A. J., Supt. Filtration, 1266 Eberhart Ave., Columbus Water Works, Columbus, Ga.

Wallis, L. E., Supt. Water Works, Elberton, Ga.

Weir, Paul, Supt. Filtration, Atlanta Water Works, 1194 Hemphill Ave., Atlanta, Ga.

Whelchel, H. E., Supt. Filter Plant, College Park, Ga.

Wilcox, W. F., Mech. Engr., Box 698, Atlanta, Ga.

Iowa Wastes Disposal Association

Lindon J. Murphy, *Secretary-Treasurer*, Iowa State College, Ames, Iowa

Ahrens, G. C., Asst. San. Engr., State Dept. of Health, Room 18, State House, Des Moines, Iowa.
Anderson, Al J., City Engineer, Fairmont, Minn.
Bartow, Edward, Prof., University of Iowa, Head, Dept. of Chem. and Chem. Eng., Iowa City, Iowa.
Bentley, Henry S., 810 S. Third St., Osage, Iowa.
Caine, Richard, Supt., Duluth Sewage Disposal Plant, 706 W. 7th St., Duluth, Minn.
Currie, C. H., Currie Engineering Co., Webster City, Iowa.
Des Moines, City of, c/o Paul Winfrey, City Engineer's Office, Des Moines, Iowa.
Doonan, R. E., City Supt., Waverly, Iowa.
Everist, Inc., L. G., c/o L. P. Ellerbroek, A College Court, Sioux City, Iowa.
Fiala, E. G., State Dept. of Health, Des Moines, Iowa.
Galligan, W. E., Civil Engineering Dept., Iowa State College, Ames, Iowa.
Green, Howard R., 208–210 Bever Bldg., Cedar Rapids, Iowa.
Hall, M. G., Hall Engineering Co., Centerville, Iowa.
Hinman, Jack J., Jr., Chief of Water Labs. Div., State Hygienic Labs., State University of Iowa, Iowa City, Iowa.
Klippel, Floyd, City Manager, City Hall, Iowa Falls, Iowa.
Levine, Max, Bacteriology Department, Iowa State College, Ames, Iowa.
Logan, John A., Prof., University of Missouri, Dept. of Civil Engineering, Columbia, Missouri.
Mark, William R., Jr., Le Mars, Iowa.
Marzee, E. J., 3231 Fourth Ave., Sioux City, Iowa.
Morrell and Co., John, Att: Mr. Frank C. Raney, Purchasing Agt., Ottumwa, Iowa.
Murphy, Lindon J., Engineering Extension Service, Iowa State College, Ames, Iowa.
Newton, City of, c/o Stanley Baker, City Hall, Newton, Iowa.
Perkins, George L., 213 1st St., N.W., Mason City, Iowa.
Richsmann, Vic, Osage, Iowa.
Ross, James S., Britt, Iowa.
Schrack, Bert, 621 1st St., S.W., Oleweiu, Iowa.
Sedlacek, A. J., Supt. of Sewage Works, Pocahontas, Iowa.
Smith, Chas. H., Supt. of Utilities, Winterset, Iowa.
Stanley, C. M., Young and Stanley, Inc., 211 Iowa Ave., Muscatine, Iowa.
Truckenmiller, E. E., Supt. Public Utilities, Sibley, Iowa.
Walker, William W., Dr., 1614 Second Ave., S.E., Cedar Rapids, Iowa.
Waterman, Earle L., Prof. of Sanitary Engineering, State University of Iowa, Iowa City, Iowa.
Whisler, Ben A., Civil Engineering Dept., Iowa State College, Ames, Iowa.
Wieters, A. H., Director, Div. of Public Health Engineering, State Dept. of Health, Des Moines, Iowa.
Wilson, C. T., 620 W. Third St., Waterloo, Iowa.
Wise, Sam, Water Supt., Manson, Iowa.
Young, Frank E., City Engineer, City Hall, Cedar Rapids, Iowa.

Kansas Water and Sewage Works Association

Earnest Boyce, *Secretary*, State Board of Health, Lawrence, Kansas

Angevine, L. C., Water and Light Supt., McPherson, Kansas.
Boyce, Earnest, Chief Engineer, State Board of Health, Lawrence, Kansas.
Boyer, J. A., Chemist, 910 Burke St., Ft. Scott, Kansas.
Chapman, R. B., 4706 Broadway Blvd., Kansas City, Missouri.
Connell, H. H., c/o Paulette and Wilson, C. E., Farmers Union Bldg., Salina, Kansas.
Cuthbertson, L., Girard, Kansas.
Diehl, Paul A., 1415 Glenarm, Denver, Colo.
Estrin, Fred, 609 New England Bldg., Kansas City, Missouri.
French, A. E., Sewage Disposal Plant, City of El Dorado, El Dorado, Kansas.

Frerking, A. G., c/o W. S. Dickey Co., Kansas City, Missouri.
German, H. L., Holton, Kansas.
Haney, Paul, Asst. Engr., 2115 Rhode Island, Lawrence, Kansas.
Hanlen, H. H., City Manager, Winfield, Kansas.
Hefling, A. W., Hefling and Hughes, Hutchinson, Kansas.
Kaler, P. E., 1522 W. 16th, Topeka, Kansas
LaFollette, R. M., 517 Finance Bldg., Kansas City, Missouri.
Lawrence, R. E., c/o Black and Veatch, Cons. Engr., 4706 Broadway, Kansas City, Missouri.
Lee, R. B., c/o City Engineer's Office, Hutchinson, Kansas.
Lingo, H. L., Water and Light Supt., Horton, Kansas.
Luebbers, Ralph H., Q. M. Office, Fort Leavenworth, Kansas.
Mortensen, F. C., Station Hospital, Ft. Leavenworth, Kansas.
Paulette, R. J., Consulting Engr., National Reserve Life Bldg., Topeka, Kansas.
Reynolds, Rex, Water Supt., Dodge City, Kansas.
Smith, Levi B., Water Supt., Paola, Kansas.
Spaeth, Julius, 334 North Tenth St., Salina, Kansas.
Sparks, R. R., Water Supt., Troy, Kansas.
Staley, H. H., 372 New England Bldg., Topeka, Kansas.
Strang, J. A., 426 Board of Trade Bldg., Kansas City, Mo.
Sulentic, S. A., 327 New England Bldg., Topeka, Kansas.
Swope, Gladys, Chemist, North Shore Sanitary District, Dahringer Road, Waukegan, Ill.
Wood, Lawrence E., c/o Paulette and Wilson, National Reserve Life Bldg., Topeka, Kansas.
Young, Lewis A., 1704 Mississippi, Lawrence, Kansas.

Maryland-Delaware Water and Sewerage Association

A. W. Blohm, *Secretary-Treasurer,* State Department of Health, 2411 N. Charles St., Baltimore, Md.

Armeling, Geo. K., 4031 Bonner Road, Baltimore, Md.
Bingley, W. McLean, The Dorr Company, 1505 Candler Building, Atlanta, Ga.
Blohm, A. W., 2411 North Charles St., Baltimore, Md.
Clement, R. C., 3213 Jocelyn St., N.W., Washington, D. C.
Cromwell, Edward C., Baltimore Sewage Treatment Plant, Colgate, Md.
Crozier, B. L., Chief Engineer, Municipal Building, Baltimore, Md.
Donaldson, Edgar F., Annapolis Water Co., R.F.D. No. 1, Annapolis, Md.
Enoch Pratt Free Library, Periodicals Dept. Cathedral, Franklin and Mulberry Sts., Baltimore, Md.
Finck, G. E., Bureau of Sewers, Municipal Building, Baltimore, Md.
Genter, Albert L., Wyman Park Apartments, Baltimore, Md.
Hall, Harry R., Deputy Chief Engr., Washington Surb. San Dist., Hyattsville, Md.
Hopkins, Ed. S., Montebello Filters, Hillen Road, Baltimore, Md.
Keefer, C. E., 1918 Mt. Royal Terrace, Baltimore, Md.
Kratz, Herman, 4200 Connecticut Ave., Baltimore, Md.
MacMurray, L. C., Res. Engineer, Md. State Dept. of Health, 2411 N. Charles St., Baltimore, Md.
Menard, Noah, Jr., Engineer, Sewage Treatment Plant, Beltsville Research Center, Beltsville, Md.
Owings, Noble L., Asst. Engineer, Washington Suburban Sanitary District, Hyattsville, Md.
Patrick, J. G., Chemist, West Va. Pulp and Paper Co., Luke, Md.
Powell, S. T., Professional Building, 303 N. Charles St., Baltimore, Md.
Shelley, F. C., 6206 Fair Oaks Ave., Baltimore, Md.
Smith, Paul L., Baltimore, Sewage Treatment Works, Colgate, Md.
State Department of Health, Bureau of Sanitary Engineering, 2411 N. Charles St., Baltimore, Md.
Unger, G. C., Jr., 97 Wine Ave., Hyattsville, Md.
Whitman, Requardt and Smith, Charles and Biddle Sts., Baltimore, Md.
Williamson, A. E., San. Engr., Tift County Health Dept., Box 456, Tifton, Ga.
Wolman, Abel, State Dept. of Health, 2411 N. Charles St., Baltimore, Md.

Michigan Sewage Works Association

W. F. Shephard, *Secretary-Treasurer,* State Dept. of Health, Lansing, Mich.

Adams, Milton P., Executive Secty., Michigan Stream Control Comm., Lansing, Mich.
Anderson, R. A., Supt. Sewage Treatment Plant, Muskegon Heights, Mich.
Bentley, Roy, Michigan Home and Training School, Lapeer, Mich.
Birkeness, O. T., Room 511, 605 W. Washington Ave., Chicago, Ill.
Board, Leonard M., St. Louis County Health Dept., Hospital North and South Road, Clayton, Mo.
Bowers, T. C., 202 East Ganson St., Jackson, Mich.
Boyd, J. W., 442 Grant St., Grand Haven, Mich.
Brown and Sons, Mason L., 120 Madison Ave., Detroit, Mich.
Chambers, Mark A., City Hall, Battle Creek, Mich.
Charlotte, City of, c/o Mr. O. E. Packard, Charlotte, Mich.
Corson, H. C., City Engineer, Birmingham, Mich.
Craun, R. D., 228 Damon St., Jackson, Mich.
Damoose, N. G., Sewage Treatment Works, Battle Creek, Mich.
Davis, M. W., 455 Norwood St., Hillsdale, Mich.
De Hooghe, Benard, Gladstone, Mich.
Dempster, A. T., 9355 Wildemere, Detroit, Mich.
Dodge, H. P., 809 Rose Ave., Ann Arbor, Mich.
Dorr, Fred., Box 717, Royal Oak, Mich.
Dowd, Ira, Sewage Treatment Plant, Flint, Mich.
Doyle, Thomas J., 274 E. Boulevard, Pontiac, Mich.
Drury, Walter R., c/o Drury and McNamee, and Shoecraft, Ann Arbor, Mich.
Eldridge, E. F., Chemistry Dept., Michigan State College, East Lansing, Mich.
Ellis, Norman T., 213 Clinton St., Grand Haven, Mich.
Fargo Engineering Co., Jackson, Mich.
Faust, R. J., Michigan Dept. of Health, Lansing, Mich.
Fishbeck, Kenneth, City Engineer's Office, Lansing, Mich.
Forton, Gerald, Supt. Sewage Treatment Plant, Traverse City, Mich.
Francis, Geo. W., Francis Engineering Company, Eddy Bldg., Saginaw, Mich.
Gates, Lloyd R., Dr., University of Michigan, 140 W. Medical Bldg., Ann Arbor, Mich.
Green, R. A., 616 Gilbert Ave., Jackson, Mich.
Gustafson, Ivar, 302 N. Harrison St., Ludington, Mich.
Habermehl, C. A., 14600 Winthrop, Detroit, Mich.
Hamill, H. H., Plymouth, Mich.
Hargraves, D. L., 107 N. Genesee Ave., Pontiac, Mich.
Hasson, H. H., c/o Van Buren County Health Dept., Paw Paw, Mich.
Hauer, Gerald, 43 Dickinson Ave., Grand Rapids, Mich.
Heeg, H. H., Sewage Treatment Plant, Howell, Mich.
Hoad, W. C., Prof. University of Michigan, Ann Arbor, Mich.
Hubbell, George, Wayne University, Detroit, Mich.
Jacka, S. C., City Engineer, Lansing, Mich.
Jackman, H. W., 501 Main St., Battle Creek, Mich.
Jackson, R. B., 527 W. Ganson St., Jackson, Mich.
Jackson, T. L., St. Ignace, Mich.
Jellema, John F., 89 E. 22nd St., Holland, Mich.
Jennings, L. R., 508 E. Main St., Owosso, Mich.
Kammerling, Lane, 194 E. 7th St., Holland, Mich.
Kelley, R. E., 119 S. Maple St., Sturgis, Mich.
Kenyon, Gale, Stream Control Comm., Lansing, Mich.
Kronbach, Allan, 615 Borgess Ave., Monroe, Mich.
Lanigan, J. A., Office of the P.W.A., Chicago, Ill.
Leemaster, J. F., 1036 Lansing Ave., Jackson, Mich.
McCallum, G. E., Sanitary Engineer, Kent County Health Dept., Grand Rapids, Mich.
McFarlane, W. D., 14365 Marlow Ave., Detroit, Mich.
McGrath, C. P., 116 Clinton St., Mt. Clemens, Mich.
McKenna, Harold R., 520 E. Third St., Flint, Mich.
Mallmann, Dr. W. L., Michigan State College, East Lansing, Mich.
Marshall, J. C., Charlevoix, Michigan.
Matthews, Richard, Analyst, City Testing Lab., Muskegon, Mich.

May, D. C., Ayres, Lewis, Norris and May, Wolverine Bldg., Ann Arbor, Mich.
Miller, Edmund C., c/o Geo. B. Gascoigne, Leader Bldg., Cleveland, Ohio.
Miller, H. E., 417 W. Engineering Bldg., University of Michigan, Ann Arbor, Mich.
Mitchell, P. T., City Manager, Petoskey, Mich.
Morrill, A. B., 13563 Birwood Ave., Detroit, Mich.
Mudgett, C. T., Sewage Treatment Works, Muskegon, Mich.
Musgrove, Robert, Sewage Treatment Works, Grand Rapids, Mich.
Norgaard, John, Sewage Treatment Plant, Escanaba, Mich.
Oeming, L. F., 1534 E. Grand River, Lansing, Mich.
Ohr, Milo F., 4200 Bedford Rd., Detroit, Mich.
Olsem, Herbert A., Michigan Municipal League, Ann Arbor, Mich.
Pate, Edwin, c/o Pate and Hirn, 532 Michigan Bldg., Detroit, Mich.
Peterson, Carl, City Manager, Muskegon, Mich.
Pierce, W. E., Whitehall, Mich.
Potts, Harry G., Pennsylvania Salt Co., Wyandotte, Mich.
Powers, Thos. J., 2506 E. Ashman St., Route No. 1, Midland, Mich.
Pulling, B. W., 800 17th St., Jackson, Mich.
Ray, Vernon X., 5160 Ternes Ave., Dearborn, Mich.
Raymond, Clare, Mason, Mich.
Raymond, N. I., 610 Pine St., Owosso, Mich.
Roddy, William J., 722 S. 16th St., Escanaba, Mich.
Roth, Albert, Hubbell, Hartgering and Roth, 2640 Buhl Bldg., Detroit, Mich.
Rumsey, James R., 75 Washington Ave., Kenmore, N. Y.
Rundell, O. L., c/o Board of Public Works, South Haven, Mich.
Sawyer, Charles, City Engineer, Traverse City, Mich.
Scarlett, John, Sanitary Inspector, Allegan Co. Health Dept., Allegan, Mich.
Schneider, Edwin C., City Hall, Fremont, Mich.
Shafter, E. M., City Manager, Royal Oak, Mich.
Shephard, W. F., Mich. Dept. of Health, Lansing, Mich.
Smith, Harold L., Alma, Mich.
Smith, Robert J., Michigan Dept. of Health, State Office Bldg., Lansing, Mich.
Smith, Walter E., Wallace and Tiernan Company, Inc., 415 Brainard St., Detroit, Mich.
Snedeker, L. La Verne, 150 S. McKenzie St., Adrian, Mich.
Sparks, Bert, Hastings, Mich.
Stielstra, Clarence, R.R. No. 4, Midland, Mich.
Tarbell, J., 1404 Fourth St., Jackson, Mich.
Theroux, Frank R., Civil Engineering School, Mich. State College, E. Lansing, Mich.
Weeber, Earle R., 1440 Mackinaw Road, S.E., Grand Rapids, Mich.
Welch, Pierre R., 701 Marquette St., Flint, Mich.
Wigg, C. V., Box 697, Bessemer, Mich.
Wolohan, L. J., 7719 Indiana Ave., Dearborn, Mich.
Wyllie, George F., 411 N. Saginaw St., Durand, Mich.
Zimmer, Walter E., City Engineer, Mason, Mich.

Missouri Water and Sewerage Conference

Warren Kramer, *Secretary*, State Board of Health, 200 Monroe St., Jefferson City, Mo.

Abner Hood Chemical Co., 107 North Montgall, Kansas City, Mo.
Archer and Co., E. T., Consulting Engineers, New England Bldg., Kansas City, Mo.
Barnes, W. E., City Engineer and Supt., Water Works, Liberty, Mo.
Black and Veatch, 4706 Broadway Blvd., Kansas City, Mo.
Brown, Hugh, Supt. Water Works, Vandalia, Mo.
Butler, E. W., International Filter Company, 1205 Oliver St., St. Louis, Mo.
Christopher, J. B., Supt. Water Works, Warrensburg, Mo.
City Water and Light Plant, c/o M. S. Hogan, Supt., West Plains, Mo.
Crane, D. Elrow, Supt., Light and Water Dept., Columbia, Mo.
Dyktor, H. G., Industrial Hygiene Engineer, St. Louis Health Dept., Municipal Courts Bldg., St. Louis, Mo.
Filby, E. L., Prin. Asst., Black and Veatch, 4706 B'way, Kansas City, Mo.
Fox, Glenn C., Supt. of Water Works, Marceline, Mo.
Fuhrman, Ralph E., Sewage Treatment Plant, Blue Plains, D. C.

Haskins, Charles A., Cons. Eng., Finance Bldg., Kansas City, Mo.
Hayob, Henry, Jr., Supt. Water Works, Marshall, Mo.
Helmreich, L. W., Pres., Capital City Water Company, Jefferson City, Mo.
Hollowell, A. Cooley, 413 Interstate Bldg., Kansas City, Mo.
Howard, R. R., Supt., Water Works, Slater, Mo.
Johnson, R. C., Mgr., Water Dept., Marshall, Mo.
Kehr, Wm. Q., Supt., Sewage Plants, Springfield, Mo.
Kramer, Warren A., State Board of Health, 200 Monroe St., Jefferson City, Mo.
McVay, Lewis, Supt. Water Works, La Plata, Mo.
Martin, J. M., Water Supt., King City, Mo.
Maryville, City of, c/o Edw. Myers, Supt., Water Works, Maryville, Mo.
Newell, H. E., Mgr., Webb City Water Dept., Webb City, Mo.
Nolte, August G., c/o State Board of Health, Jefferson City, Mo.
Pirner, George, Capital City Water Co., Jefferson City, Mo.
Pollard, R. S., Hon., Mayor, Columbia, Mo.
Russell and Axon, 4903 Delmar Blvd., St. Louis, Mo.
St. Louis Public Library, Olive, 13th and 14th Sts., St. Louis, Mo.
Stadler, C. C., Capital City Water Co., Jefferson City, Mo.
Stiers, John, Capital City Water Co., Jefferson City, Mo.
Sween, J. A., Supt. Water Works, Hamilton, Mo.
Thain, A. E., Supt. Water Works, Neosho, Mo.
Thompson, Homer F., 1st Lt. Engineer, Res. Co. 2730, CCC, Maysville, Mo.
Weir, W. V., St. Louis County Water Co., 6600 Delmar Ave., University City, Mo.
Zimmer, J. Frank., Supt., Municipal Water Dept., Farmington, Mo.

New England Sewage Works Association

F. Wellington Gilcreas, *Secretary-Treasurer*, Division of Labs. and Research, N. Y. State Dept. of Health, Albany, N. Y.

Adams, George O., Lawrence Experiment Station, State Dept. of Health, Lawrence, Mass.
Agar, Charles G., Div. of Sanitation, State Dept. of Health, Albany, N. Y.
Allen, Herbert B., Sewage Plant Operator, Sewage Treatment Plant, Fitchburg, Mass.
Almquist, Frederick O. A., Conn. State Dept. of Health, State Office Bldg., Hartford, Conn.
Baldwin, C. W., Syntron Company, 230 Congress St., Boston, Mass.
Barbour, Frank A., 1119 Tremont Bldg., Boston, Mass.
Benford, William R., Brown University, Providence, R. I.
Bogren, George G., Weston and Sampson, 14 Beacon St., Boston, Mass.
Bolde, Abraham C., Room 511-a, State House, Boston, Mass.
Bowers, Samuel W., c/o MacKenzie and Bowers, Southington, Conn.
Brigham, Harold L., Water and Sewer Comm., Malboro, Mass.
Brooks, John H., Jr., E. Worcester St., Worcester, Mass.
Brule, Abundius A., 157 Chestnut St., Central Falls, R. I.
Buck, Robinson D., 650 Main St., Hartford, Conn.
Bugbee, Julius W., Supt. Sewage Disposal Works, 25 New York Ave., Providence, R. I.
Burden, Harry P., Assoc. Prof., Tufts College, Medford, Mass.
Burdoin, Allen J., 12 Pearl St., c/o Howard M. Turner, Boston, Mass.
Calvert, John T., 61, Half Moon Lane, Herne Hill, London, S.E. 24, England.
Camp, Thomas R., Assoc. Prof. Massachusetts Inst. of Tech., Cambridge, Mass.
Campbell, Arthur T., 165 Capitol Ave., Hartford, Conn.
Carpenter, Howard F., 15 Bradley St., Providence, R. I.
Carson, Caryl C., Box 1139, Hartford, Conn.
Carter Co., Ralph B., Att: Mr. J. W. VanAtta, 53 Park Place, N. Y. C.
Cary, Willis E., 5 Chesterfield Rd., Worcester, Mass.
Chase, E. Sherman, Metcalf and Eddy, 1300 Statler Bldg., Boston, Mass.
Clark, H. W., 11 Beacon St., Boston, Mass.
Clarke, V. B., Box 582, Ansonia, Conn.
Cobb, Edwin B., 142 Vernon St., Norwood, Mass.

Coburn, S. E., 1300 Statler Bldg., Boston, Mass.
Cohn, Morris M., 1101 Lexington Ave., Schenectady, N. Y.
Copeland, William R., Room 317, State Office Bldg., Hartford, Conn.
Coy, Arthur H., Water and Sewer Dept., Westerly, R. I.
Cutting, Merritt, Auburn St., Cherry Valley, Worcester, Mass.
Davis, L. A., City Engr., Danbury, Conn.
De Haas, Nicholas, Box 176, Linwood, Mass.
Dion, Clarence K., 28 Chester Ave., Westerly, R. I.
Doggett, William H., Sandy Valley Road, Dedham, Mass.
Du Bois, Isadore J., 50 Walnut St., Putnam, Conn.
Eddy, Harrison P., Jr., 1300 Statler Bldg., Boston, Mass.
Edwards, Gail P., 104 Summer St., Malden, Mass.
Eliassen, Rolf, The Dorr Company, Inc., Westport, Conn.
Ellsworth, Samuel M., Consulting Engineer, 12 Pearl St., Boston, Mass.
Enslow, L. H., Water Works and Sewerage, 155 E. 44th St., New York, N. Y.
Fair, Gordon M., Prof., 112 Pierce Hall, Cambridge, Mass.
Fales, Almon L., c/o Metcalf and Eddy, Statler Bldg., Boston, Mass.
Farnham, Arthur B., City Engineer, Pittsfield, Mass.
Fleming, Paul V., 1272 Mass. Ave., North Adams, Mass.
Flood, Frank L., c/o Metcalf and Eddy, Statler Bldg., Boston, Mass.
Foote, Kenneth E., Room 501, Hall of Records, New Haven, Conn.
Gage, Stephen DeM., 177 Arnold Ave., Edgewood, R. I.
Gilbert, Joseph J., 201 Wheatsheaf Lane, Abington, Pa.
Gilcreas, F., Wellington, Secty., Division of Labs. and Research, New Scotland Ave., Albany, N. Y.
Giles, J. Henry L., State Dept. of Health, State Office Bldg., Hartford, Conn.
Gisborne, Frank R., Operator, Arcadia Road, Old Greenwich, Conn.
Greenleaf, John W., Jr., 14 Beacon St., Boston, Mass.
Greenwich Sewer Commission, Room No. 7, Town Bldg., Greenwich, Conn.
Griffin, Guy E., Virginia Court, Greenwich, Conn.
Haley, F. W., c/o F. A. Barbour, 1119 Tremont Bldg., Boston, Mass.
Hanrath, William J., Sewage Pumping Sta., Pittsfield, Mass.
Hanson, Christopher, Sewage Disposal Works, Marlboro, Mass.
Harper, M. J., Merco Nordstrom Valve Co., 50 Church St., New York City, N. Y.
Hill, G. Everett, 45 7th Ave., New York City.
Holmes, Glenn W., 1219 N. Adams St., Arlington, Va.
Holmes, Harry E., Mass. State Dept. of Health, State House, Boston, Mass.
Holmgren, Richard F., Chief Engineer, Water Resources Board, Concord, N. H.
Horne, Ralph W., 11 Beacon St., Boston, Mass.
Houser, George C., 220 Clyde St., Brookline, Mass.
Howard, P. F., Cottage Park Road, Winthrop, Mass.
Jackson, J. Frederick, 36 Cannon St., Hamden, Conn.
Jenckes, J. Franklin, Jr., Fields Point Mfg. Corp., Providence, R. I.
Johnson, Eskil C., Board of Purification of Waters, State Office Bldg., Room 327, Providence, R. I.
Joyce, Clarence M., Du Pont Viscoloid Co., Leominster, Mass.
Kelsey, Walter, c/o Lord & Burnham Co., Irvington, N. Y.
Kendrick, Walter L., Sewer Maintenance Dept., 37 Ernest St., Providence, R. I.
Knowlton, Kenneth F., 11 Roxbury Ave., Natick, Mass.
Kunsch, Walter, 25 E. Pearl St., Danbury, Conn.
Jordan, Edward C., 21 Lincoln St., Portland, Me.
La Croix, Louis, 45 Maple St., Spencer, Mass.
Lamb, Clarence F., Waterman Engineering Co., 86 Weybosset St., Providence, R. I.
Lanphear, Roy S., Worcester Sewage Treatment Plant, Post Office Station C, Worcester, Mass.
Lingley, Ralph G., 33 City Hall, Worcester, Mass.
Locke, Edw. A., 21 Forster St., Hartford, Conn.
Lumbert, William J., 36 Country Way, Greenbush, Mass.
McCall, Joseph F., U. S. Veterans' Bureau Hospital, Bedford, Mass.
McCormack, John H., Public Works Office, City Hall, Providence, R. I.

McVey, John F., Jr., 511-A State House, Boston, Mass.
Maguire, Chas., Comm. of Public Works, City Hall, Providence, R. I.
Marrah, Edwin K., 108 Park Ave., Woonsocket, R. I.
Martzell, Paul C., 60 Mead Ave., Port Chester, N. Y.
Merrill, Walter E., 511-A State House, Boston, Mass.
Meyer, Carl, Sewage Treatment Plant, Rockville, Conn.
Moat, C. P., Chemist, 2 Colchester Ave., Burlington, Vt.
Moore, Edward W., 33 Gilbert Road, Belmont, Mass.
Morgan, Edward F., Jr., Supt. of Public Works, Hudson, Mass.
Muldoon, Joseph A., 849 Hancock Ave., Bridgeport, Conn.
Newlands, James A., Pres., Henry Souther Engineering Co., 11 Laurel St., Hartford, Conn.
Nicoli, Frank A., Y. M. C. A. Dorms., Huntington Ave., Boston, Mass.
Perry, William W., 814 Hope St., P.O. Box 85, Bristol, R. I.
Petrie, William P., Supt., Sewage Disposal Plant, Norwalk, Conn.
Pitkin, Ward H., 242–15 Church St., Douglaston, N. Y.
Pool, Charles L., R. I. Public Health Comm., 335 State Office Bldg., Providence, R. I.
Pratt, Gilbert H., 68 Brookline Ave., Boston, Mass.
Proudman, Chester F., New Canaan Sewage Disposal Plant, New Canaan, Conn.
Quinn, Francis T., 116 South St., Westboro, Mass.
Quinn, Thomas A., 116 South St., Westboro, Mass.
Ray, William P., 30 South Cotton St., Leominster, Mass.
Richardson, Charles G., Builders Iron Foundry, Providence, R. I.
Robb, Charles G., Engineering Dept., Municipal Bldg., Hartford, Conn.
Robinson, Leonard C., Supt. Water and Sewer Dept., Concord, Mass.
Roche, Edward C., 3243 Boulevard Place, Indianapolis, Ind.
Sanderson, W. W., 17 William Jackson Ave., Brighton, Mass.
Sawyer, Robert W., Jr., c/o Malcolm Pirnie, 25 West 43rd St., New York City.
Scott, Warren J., 34 Garfield Rd., West Hartford, Conn.
Shea, Walter J., 327 State Office Bldg., Providence, R. I.
Shepperd, Frederick, "Municipal Sanitation," 24 W. 40th St., New York, N. Y.
Sherman, Leslie K., 839 Farmington Ave., West Hartford, Conn.
Sieverding, O. C., 25 Somerset St., Elmwood, Conn.
Smith, Fred E., Cambridge Water Purification Plant, Fresh Pond P'kway, Cambridge, Mass.
Snell, J. R., 50 Wendell St., Cambridge, Mass.
Show, Willis J., State Water Commission, State Office Bldg., Hartford, Conn.
Solander, Arvo A., 34 West St., Winchendon, Mass.
Soule, Ralph M., 511-A State House, Boston, Mass.
Sprague, E. H., Prof., University of Maine, Orono, Me.
Sterling, Clarence I., Mass. Dept. of Public Health, 145 State St., Springfield, Mass.
Stock, Mitchell B., P.O. Box 804, Bridgeport, Conn.
Sullivan, Ernest J., 511-a State House, Boston, Mass.
Suttie, R. H., Prof., Dept. of Civil Engineering, Yale University, New Haven, Conn.
Szymanski, John R., New Britain Treatment Plant, New Britain, Conn.
Thompson, E. H., 1308 Elm St., Stratford, Conn.
Thompson, Robert B., 221 N. La Salle St., The Dorr Company, Inc., Chicago, Ill.
Tierney, Lawrence J. J., 518 Rice Bldg., 10 High St., Boston, Mass.
Trager, Leonard W., N. H. State Board of Health, Concord, N. H.
Van Kleeck, LeRoy W., State Dept. of Health, State Office Bldg., Hartford, Conn.
Wadhams, Gen. S. H., State Water Comm., State Office Bldg., Hartford, Conn.
Walker, Philip B., 18 Summit St., Whitinsville, Mass.
Watertown Fire Dist., Watertown, Conn.
Watters, George E., 536 Montauk Ave., New London, Conn.
Wentworth, John P., 1300 Statler Bldg., Boston, Mass.
Weston, Arthur D., Room 511, State House, Boston, Mass.
Weston, R. S., Cons. Eng., 14 Beacon St., Boston, Mass.
Whipple, Melville C., 112 Pierce Hall, Cambridge, Mass.
White, Nelson C., c/o Fields Point Mfg. Corp., Providence, R. I.

Whitlock, Henry C., City Hall, Waterbury, Conn.

Wiggin, David C., Jr., Apt. 45, 10A Chauncy St., Cambridge, Mass.

Worthington, Erastus, Insurance Bldg., Dedham, Mass.

Wuraftic, Joseph, 335 State Office Bldg., Providence, R. I.

New Jersey Sewage Conference

Richard C. Smith, *Secretary*, 29 High St., Glen Ridge, N. J.

Ackerman, A. P., c/o P.W.A., Post Office Bldg., Newark, N. J.

Atkinson, Asher, City Engineer, City Hall, New Brunswick, N. J.

Barbahenn, E. W., 13 Highland Place, Maplewood, N. J.

Bender, E., 1215 S. Edgewood St., W. Philadelphia, Penna.

Bonacci, L. N., Research Corp., Bound Brook, N. J.

Boreiszo, J., 39 Clay St., Milltown, N. J.

Boughten, P. S., Cedar Grove, N. J.

Burack, W. D., 90 Sycamore Ave., Livingston, N. J.

Cameron, Geo., 1905 Kuehnle Ave., Venice Park, Atlantic City, N. J.

Chamberlin, Noel S., 133 Vincent Ave., Mercerville, N. J.

Cleary, Edward J., Old Quarry Road, Upper Montclair, N. J.

Coe, J. H., Englewood Sewerage Trust Co., Englewood, N. J.

Corson, B. I., Camden County Vocational School, Merchantville, N. J.

Cowles, M. W., Hackensack Water Co., Dept. Filtration and Sanitation, New Milford, N. J.

Decker, E. P., City Hall, Newark, N. J.

Evans, F. M., Boro Engineer, Glen Rock, N. J.

Farrant, James, 443 East 29th St., Paterson, N. J.

Gehm, Harry Willard, Agricultural Experiment Sta., New Brunswick, N. J.

Gibbons, M. M., Box 162, Rahway, N. J.

Harley, Frank E., Fair Lawn Radburn Trust Co. Bldg., Fair Lawn, N. J.

Harris, George W., 484 Bloomfield Ave., Montclair, N. J.

Henderson, C. N., 4 Beechwood Place, New Brunswick, N. J.

Heukelekian, H., Short Course Bldg., Agricultural Experiment Sta., New Brunswick, N. J.

Ingols, Robert, Agricultural Experiment Sta., New Brunswick, N. J.

Kachorsky, M. S., Manville Sewerage Works, Manville, N. J.

Kupper, C. J., Bound Brook, N. J.

Lacy, I. O., 395 Catherine St., Somerville, N. J.

Lendall, Prof. Harry N., Dept. of Municipal and San. Engineering, Rutgers University, New Brunswick, N. J.

Lindsey, R. W., 443 Second Ave., Lyndhurst, N. J.

Lipman, Dr. J. G., Director, N. J. Agricultural Experiment Sta., New Brunswick, N. J.

Mallalieu, W. C., P.O. Box 384, Boonton, N. J.

Miles, Henry J., P.O. Box 966, Chapel Hill, N. C.

Missonelli, S., 118 N. Eight St., Hawthorne, N. J.

Morgan, John E., 918 North Third St., Camden, N. J.

Norcom, George D., 90 Broad St., New York, N. Y.

Ocean City Sewer Service Co., Ocean City, N. J.

Orchard, W. J., Sales Mgr., Wallace & Tiernan Co., Newark, N. J.

Orford, H. E., 1468 E. 115th St., Cleveland, Ohio.

Porges, Ralph, 1000 N. Elm St., Greensboro, N. C.

Ridenour, G. M., Agricultural Experiment Station, New Brunswick, N. J.

Roberts, L. M., 219 Willow St., Bound Brook, N. J.

Rodda, Wm., Jr., 67 Ryerson Ave., Newton, N. J.

Row, R. R., 50 Church St., New York, N. Y.

Rudolfs, Dr. Willem, Short Course Bldg., Agricultural Experiment Sta., New Brunswick, N. J.

Sandford, Chester, 223 Lenox Ave., South Orange, N. J.

Setter, Lloyd R., Box 106, New York University, University Heights, N. Y. City, N. Y.

Seydel, Herman, The Cloroben Corp., 90 Forest St., Jersey City, N. J.

Simmerman, John S., 215 Wildwood Ave., Pitman, N. J.

Slagle, E. A., Dr., 100 Hudson Ave., No. Plainfield, N. J.

Smith, P. A., 66 Stanley Road, South Orange, N. J.

Smith, R. C., 24 High St., Glen Ridge, N. J.
Strahan, Joe, 8th Ave. and Ocean, Asbury Park, N. J.
Tentschert, Francis, 14 Whittier St., East Orange, N. J.
Trubnick, Eugene, 784 High St., Newark, N. J.
Van Derwerker, Ralph J., 961 Summit Ave., Westfield, N. J.
Weiss, H., Sewer Supt., East Paterson, N. J.
West, Leslie E., 105 Mill Road, Irvington, N. J.
Wittwer, Norman C., P.O. Box 186, Rahway, N. J.

New York State Sewage Works Association

A. S. Bedell, *Secretary-Treasurer*, State Department of Health, Albany, N. Y.

Abeles, Joseph C., 170 West 73rd St., New York, N. Y.
Abrams, M. F., 17 Battery Place, New York, N. Y.
Aeryns, Albert N., 716 Greenwood Ave., Brooklyn, N. Y.
Agar, Charles C., Div. of Sanitation, State Dept. of Health, Albany, N. Y.
Albertson, J. G., 663 Orchard St., Oradell. N. J.
Allen, A. F., State Dept. of Health, State Office Bldg., Albany, N. Y.
Althouse, Raymond R., 95 Elmwood Ave., Union, N. J.
American Wells Works, Inc., Att: Mr. G. H. Gaus, Mgr., 165 Broadway, New York, N. Y.
Ancell, J. H., Municipal Engr., 234 West 13th St., New York, N. Y.
Andersen, C. George, 66 Sherman Ave., Rockville Centre, N. Y.
Anderson, S. P., Pilgrim State Hospital, Brentwood, N. Y.
Andrews, Harry S., City Hall, Fulton, N. Y.
Angell, J. M., Jr., Gillette Publishing Co., 155 E. 44th St., New York, N. Y.
Artese, Philip, 751 East 224th St., Bronx, N. Y.
Asch, Abram B., 10 East 40th St., New York, N. Y.
Ashe, John F., 22 Homan Blvd., Hempstead, L. I., N. Y.
Bahl, W. G., Jeffrey Manufacturing Co., 30 Church St., New York, N. Y.
Baker, Roy, 70 South Bayles Ave., Port Washington, N. Y.
Bardet, Paul E., Jamaica Disposal Plant, 150th Ave., 132d St., South Ozone Park, N. Y.
Barker, Stanley T., State Dept. of Health, State Office Bldg., Albany, N. Y.
Barnes, Robert J., 20 Fifth Ave., Oneonta, N. Y.
Barron, James L., 20 North Broadway, White Plains, N. Y.
Bates, R. D., State Dept. of Health, 65 Court Street, Buffalo, New York.
Bauer, William, High St., Garnerville, N. Y.
Becker, Hubert Jr., Sewage Plant, Wards Island, N. Y.
Bedell, A. S., Division of Sanitation, State Dept. of Health, Albany, N. Y.
Bell, E. Arthur, Box 41, Essex Falls, N. J.
Bengi, Nejdet A., c/o A. C. Holmquist, State Dept. of Health, Albany, N. Y.
Benjamin, Leland F., 17 Erie Blvd., Canajoharie, N. Y.
Bennett, Quentin R., 2 Annette Road, Merrick, L. I., N. Y.
Bernhardt, Carl J., 400 Elmwood, Buffalo, N. Y.
Bertino, Fred, 404 West 48th St., New York, N. Y.
Besselievre, Edmund B., Room 709, Edificio Volta, Avenida R. S. Pena 832, Buenos Aires, Argentina, S. A.
Best, Robert B., 71 Maple St., Great Neck, N. Y.
Best, William R., Glenridge Sanatorium, Schenectady, N. Y.
Besthoff, Silas, 22 East 40th St., New York, N. Y.
Bevan, John G., Guggenheim Bros., 3771 Tenth Ave., New York, N. Y.
Beyer, William T., c/o Ingersoll Rand Co., 11 Broadway, New York, N. Y.
Bidwell, Milton H., 70 Stevens St., Oceanside, N. Y.
Biele, F. J., 184 Nassau Ave., Huntington, N. Y.
Bingham, Chris F., The Columbia Alkali Corp., 30 Rockefeller Plaza, New York, N. Y.
Board of Sewer Commissioners, Belgrave Sewer District, Great Neck, N. Y.
Bogert, C. L., 30 Church St., New York, N. Y.
Bowe, Thomas F., 110 William St., New York, N. Y.
Boyce, Ralph E., Nassau, N. Y.

Boyd, George E., c/o Wailes Dove Hermiston Corp., 17 Battery Place, New York, N. Y.
Bradner, B. E., 108 Ellsworth Ave., Harrison, N. Y.
Breuchand, Jules R., 155 East 44th St., New York, N. Y.
Brigham, John C., State Dept. of Health, State Office Building, Albany, N. Y.
Brown, Harry, 47 Carlton, Port Washington, N. Y.
Brown, Thomas P., 214 Park Ave., Williston Park, N. Y.
Bruckman, M. A., 50 Estall Road, Rochester, N. Y.
Brumbaugh, W. V., National Lime Association, 927 15th St., N.W., Washington, D. C.
Buck, George H., 55 Cherry St., Elizabeth, N. J.
Burczak, William J., 8 Byrd St., Glen Cove, N. Y.
Butkiewicz, Joseph W., 112 Seventh St., New York, N. Y.
Butler, Manning J., 422 Beach 123d St., Rockaway Park, L. I.
Caird, James M., Cannon Bldg., Troy, N. Y.
Capen, Jr., Charles H., 8 Florence Place, West Orange, N. J.
Carborundum Co., The, Att: Mr. Frank C. Roe, San. Engr., Niagara Falls, N. Y.
Carey, John E., 59 South Hawk St., Albany, N. Y.
Carmichael, David W., P.O. Box 189, Yorktown Heights, N. Y.
Carpenter, Harry C., 218 Wisner Ave., Middletown, N. Y.
Carpenter, L. V., New York University, University Heights, New York, N. Y.
Carpenter, William T., 125 Worth St., New York, N. Y.
Carter Co., Ralph B., Att: Mr. J. W. Van Atta, 53 Park Place, New York, N. Y.
Cary, F. Arthur, 185 North Main St., Fairport, N. Y.
Caverno, C. W., 122 E. 42d St., New York, N. Y.
Cerny, Paul J., 441 Lexington Ave., Room 1102, New York, N. Y.
Chadsey, William H., 1186 Ardsley Road, Schenectady, N. Y.
Chamberlain, Wm. T., 129 Columbia Heights, Brooklyn, N. Y.
Chapman Valve Manufacturing Co., 203 Hampshire St., Indian Orchard, Mass.
Chase, E. Sherman, Metcalf and Eddy, 1300 Statler Bldg., Boston, Mass.
Christian, James B., 18 Madison Ave., Rockeville Centre, L. I., N. Y.
Cohn, Morris M., 1101 Lexington Ave., Schenectady, N. Y.
Collyer, J. C., Room 2100, Municipal Bldg., New York, N. Y.
Compson, Louis D., Ames Pump Co., Inc., 30 Church St., New York, New York.
Comstock, Walter C., 135 North 11th St., New Hyde Park, N. Y.
Conner, H. McKean, 3804 Greystone Ave., Bronx, N. Y.
Cook, Rodney E., Main Street, Riverhead, N. Y.
Cookinham, R. S., 2700 Sunset Ave., Utica, N. Y.
Copeland, William R., State Office Bldg., Hartford, Conn.
Corwin, Wilfred B., 37 Lansdowne Drive, Larchmont, N. Y.
Costello, John J., 631 Perine St., Elmira, N. Y.
Cotton, Edwin R., 70 Monroe Drive, Williamsville, N. Y.
Cowell, John E., 160 School St., Oyster Bay, N. Y.
Cowing, Roy T., 135 Ohio Ave., West Springfield, Mass.
Cowles, M. Warren, Hackensack Water Co., New Milford, N. J.
Cox, C. R., State Dept. of Health, Albany, N. Y.
Crane, Robert, 200 Claremont Ave., Apt. 6, New York, N. Y.
Daidone, A. J., Dept. of Sanitation, 125 Worth St., New York, N. Y.
Danisch, Charles A., Newman St., Islip, N. Y.
Dappert, Anselmo F., R. F. D., Delmar, N. Y.
Davis, Walter S., 686 Myrtle Ave., Albany, N. Y.
Deming, Harold A., 323 East Filburt Place, East Rochester, N. Y.
Devendorf, Earl, State Dept. of Health, Albany, N. Y.
Diehl, H. B., Reeves Pulley Co., 76 Dey St., New York, N. Y.
Dilles, Paul F., 3575 Broadway, New York, N. Y.
Dobson, William T., 5621 Grand Central Terminal, New York, N. Y.
Dobstaff, Sr., Robert W., 135 Aurora Ave., Gardenville, N. Y.
Dolomite Products Co., 183 Main St., E., Room 544, Rochester, N. Y.
Doman, Joseph, 69 Osborne Ave., East Norwalk, Conn.
Donaldson, Wellington, 125 Worth St., Varick St. Station, New York, N. Y.

Dosch, Doron, c/o Hitchings and Co., Elizabeth, N. J.
Dougherty, Patrick F., 116 Park St., Ithaca, N. Y.
Downes, John R., Supt. Joint Sewage Treatment Works, Bound Brook, N. J.
Drexel, Frederick, 6266 60th Drive, Maspeth, N. Y.
Dunne, E. R., Professional Bldg., Lynbrook, N. Y.
Dyckman, Warren W., Room 2100, Municipal Bldg., New York, N. Y.
Ehle, Virgil, 21 N. Main St., Gloversville, N. Y.
Eldridge, Frank C., 42–25 215th St., Bayside, N. Y.
Enslow, L. H., 155 East 44th St., New York, N. Y.
Erdwurm, Emil, 1137 Roanoke Ave., Far Rockaway, N. Y.
Erickson, Erick B., 1711 East Capitol St., Washington, D. C.
Eustance, Harry W., 40 Cottonwood Drive, Rochester, N. Y.
Evans, Byron B., Wassaic State School, Wassaic, N. Y.
Evans, D. A., P.O. Box 862, Reading, Penna.
Faber, Harry A., 50 East 41st St., New York, N. Y.
Fair, Gordon M., 112 Pierce Hall, Harvard University, Cambridge, Mass.
Fallon, Joseph G., Kings Park State Hospital, Kings Park, L. I.
Fedeler, John H., Jr., Filtration Engineers, Inc., 858 Summer Ave., Newark, N. J.
Feigel, John H., 38 Dakota St., Apt. 5, Buffalo, N. Y.
Fenger, J. W., 24 Idlewood Place, Hamburg, N. Y.
Fenton, John V., Professional Bldg., Lynbrook, N. Y.
Fernandez, John U., 1950 E. 29th St., Brooklyn, N. Y.
Field, W. T., Watertown, N. Y.
Firth, Elmer W., 21–10 49th Ave., Long Island City, N. Y.
Fischer, Anthony J., c/o The Door Co., Inc., 370 Lexington Ave., New York, N. Y.
Fischer, Philip C., 110 Bennett Ave., Yonkers, N. Y.
Fitzgerald, J. J., Municipal Engineer, 17 Oswego Ave., Long Beach, N. Y.
Fitz-Simons, Richard H., 225 Raymond St., Rockeville Centre, N. Y.
Five, Helge, 4 Maple Drive, Great Neck, N. Y.
Foley, William M., Schenectady County Home, Hetcheltown Road, Schenectady, N. Y.
Foote, A. J., 2 East Ave., Larchmont, N. Y.
Forbes, Albert F., Box 285, Watkins Glen, N. Y.
Fort, Edwin J., 54 Lafayette St., New York, N. Y.
Fortenbaugh, J. Warren, 155 Hamlin Road, Buffalo, N. Y.
Gardner, George W., Miller Bldg., Lowville, N. Y.
Gascoigne, Geo. B., Sanitary Engineer, Euclid Ave. at East 9th St., Cleveland, Ohio.
Gates, Justin F., James St., Middletown, N. Y.
Gavett, Weston, 973 Kenyon Ave., Plainfield, N. J.
Gelbke, Arthur W., 104–18 122d St., Richmond Hill, N. Y.
Gewecke, Gordon C., 411 North Village Ave., Rockville Centre, N. Y.
Gilereas, F. Wellington, Division of Laboratories, State Dept. of Health, Albany, N. Y.
Glasser, Arthur F., 530 Academy Ave., Sewickley, Penna.
Glynn, William J., Frazier St., Brockport, N. Y.
Goodenough, Frank H., 90 Concord Ave., White Plains, N. Y.
Gorman, Richard C., Jr., 44 Genesee St., Hornell, N. Y.
Gould, Richard, H., 125 Worth St., New York, N. Y.
Grabois, Bernard, 349 E. 32d St., New York, N. Y.
Grace, Francis J., 174 West 65th St., New York, N. Y.
Greig, John M. M., 30 Church St., New York, N. Y.
Grieff, Victor C., 173 Beach 139th St., Belle Harbor, N. Y.
Grosso, Frank A., 117–41 Maisden St., Jamaica, N. Y.
Haemmerlein, Victor E., Village Hall, East Aurora, N. Y.
Hale, Arnold H., Linden Road, Route No. 3, Brighton, N. Y.
Hall, Frank H., 341 Willis Ave., Mineola, N. Y.
Hall, Frederic B., 36 State St., Albany, N. Y.
Hallock, Emerson C., 6 Northview Place, White Plains, N. Y.
Halpin, John, 18 Park Ave., Port Washington, N. Y.
Hamm, William C., 9 Locust Ave., Port Washington, N. Y.
Hammond, F. G., 1 Park Place, Canton, N. Y.
Hanson, August E., 415 Lexington Ave., New York, N. Y.

Hardenbergh, W. A., 310 East 45th St., New York, N. Y.
Harding, J. C., 19 East Main St., Mt. Kisco, N. Y.
Hardinge Company, F. E. Finch, Rep., York, Penna.
Harrison, Edward F., 2450 North Broad St., Philadelphia, Penna.
Hayes, John A., 99 South St., Warwick, N. Y.
Hedgepeth, L. L., Research Chemist, Pa. Salt Manufacturing Co., 1000 Widener Bldg., Philadelphia, Penna.
Henderson, Chas. F., 10 School St., Port Washington, N. Y.
Hendon, H. H., 51 Norman Drive, Colonial Hills, Birmingham, Ala.
Henkel, George E., 80–12 Austin St., Kew Gardens, N. Y.
Herberger, Arthur Henry, 200 W. Merrick Road, Freeport, N. Y.
Hertzenberg, Robert L., 8217 24th Ave., Brooklyn, N. Y.
Hess, Seth G., 242 West 76th St., New York, N. Y.
Heubi, Thomas, 45 Washington Ave., Fredonia, N. Y.
Hevenor, Gloster P., 52 Vanderbilt Ave., New York, N. Y.
Highberger, W. W., 445 Gramatan Ave., Mt. Vernon, N. Y.
Hill, G. Everett, 45 Seventh Ave., New York, N. Y.
Hill, Milton T., 84 Carter St., Newburgh, N. Y.
Hobbs, Harold Wayne, Agricultural Engr., Soil Conservation Service, Bath, N. Y.
Hoey, John B., 477 Middle Neck Road, Great Neck, N. Y.
Hogan, James W. T., 543 Union Ave., New York, N. Y.
Hogan, William J., 574 Willow Ave., Cedarhurst, N. Y.
Holbrook, A. R., 2104 White Ave., Knoxville, Tenn.
Holdredge, Leigh I., 27 Ford Ave., Oneonta, N. Y.
Holland, Frank H., 312 Archer St., Freeport, N. Y.
Holmes, Glenn D., 109 County Court House, Syracuse, N. Y.
Holmquist, Chas. A., State Dept. of Health, Albany, N. Y.
Hopkins, Charles C., 349 Cutler Building, Rochester, N. Y.
Hopkins, L. S. R., 76 William St., New York, N. Y.
Horton, Theodore, 352 State St., Albany, N. Y.
Hotchkiss, H. T., Jr., Supervising Chemist, Municipal Bldg., Larchmont, N. Y.
Howell, Carl L., Room 427, Municipal Bldg., Buffalo, N. Y.
Hubbard, Winfred D., 145 Pearl St., Kingston, N. Y.
Huntington Board of Sewer Commissioners, Huntington Sewer District, Huntingdon, N. Y.
Hurst, William O., Millbrook, N. Y.
Illig, Louis, Harlem Valley State Hospital, Wingdale, N. Y.
Industrial Chemical Sales Co., Inc., 230 Park Ave., Att: Mr. Noel Statham, New York, N. Y.
Inertol Company, 401 Broadway, New York, N. Y.
Iscol, George, 125 Worth St., Room 822, New York, N. Y.
Jablon, Fred M., P.O. Box 493, Great Neck, N. Y.
Jendrick, Otto J., Harlem Valley State Hospital, Wingdale, N. Y.
Johnson, Chester, 117 Bedford Ave., Freeport, L. I., N. Y.
Johnson, Herbert O., 7 Chelsea Place, Great Neck, N. Y.
Jones, Daniel, 324 North Ave., New Rochelle, N. Y.
Jones, Elmer, Kings Park State Hospital, Kings Park, N. Y.
Jones, E. M., Sales Engr., 26 W. Pamona St., Philadelphia, Penna.
Jones, J. W., 125 Worth St., Room 813, New York, N. Y.
Jost, Charles F., 112 East 19th St., New York, N. Y.
Kaiser, William B., Harlem Valley State Hospital, Wingdale, N. Y.
Kass, Nathan I., 167 Beaumont St., Brooklyn, N. Y.
Keehan, Daniel B., 268 E. 143d St., New York, N. Y.
Keirn, K. A., 293 Larkin St., Buffalo, N. Y.
Kelly, Clarence, 407 Lawrence Ave., Lawrence, N. Y.
Kelly, Cornelius B., Jr., 186 No. Columbus Ave., Freeport, N. Y.
Kelsey, Walter, c/o Lord and Burnham Co., Irvington, N. Y.
Kemp, Harold A., 118 Harrison Ave., Westfield, N. J.
Kennedy, William, Huntington Sewer Plant, Huntington, N. Y.
Kerslake, James E., State Dept. of Health, State Office Bldg., Albany, N. Y.
Ketcham, Joseph M., Gilbert St., Northport, N. Y.

Kiker, John E., Jr., c/o Dr. Roberts, DSHO, N. Y. State Dept. of Health, 54 Noxon St., Poughkeepsie N. Y.
Kilcawley, Edward J., 41 Belle Ave., Troy, N. Y.
Kirsner, Charles, 125 Spruce St., Cedarhurst, N. Y.
Kivell, Wayne A., c/o The Dorr Company, 570 Lexington Ave., New York, N. Y.
Klinck, Frank, 408 Westminister Road, Cedarhurst, N. Y.
Knox, Stuart K., 25 Warfield Road, Upper Montclair, N. J.
Kotzenberg, William J., P.O. Box 176, Wingdale, N. Y.
Kozma, Albert B., 27 Gilbert Place, West Orange, N. J.
Kurtz, A. Lawrie, 2358 N. 58th St., Milwaukee, Wisconsin.
Lager, Carl, Baldwinsville, N. Y.
Lambert, Francis J., Sewage Disposal Plant, Batavia, N. Y.
Lange, John F., 72 School St., Glen Cove, N. Y.
Langford, Leonard L., 441 Lexington Ave., New York, N. Y.
Larkin, W. H., 90 North St., Middletown, N. Y.
Larsen, Ernest A., 22 Grant Ave., Geneva, N. Y.
Laughlin, William G., 10 E. 40th St., New York, N. Y.
LaValley, Edward C., 227 Eastchester Road, New Rochelle, N. Y.
Lawlor, Thomas F., 140 S. Cherry St., Poughkeepsie, N. Y.
Lehr, Eugene L., 266 Fulton Ave., Hempstead, N. Y.
Leiby, F. E., 78 Elmwood Ave., Rye, N. Y.
Leigh, Harry W., Tuxedo Park, N. Y.
Lellis, David W., 216 Brower Ave., Rockville Center, N. Y.
Levy, Harry W., 2129 Municipal Bldg., New York, N. Y.
Lewis, John V., 54 Court St., Rochester, N. Y.
Link-Belt Co., M. B. Tark, Rep., Philadelphia, Penna.
Lippelt, Hans B., 9428 78th St., Ozone Park, N. Y.
Lord and Burnham Co., 2 Main St., Irvington, N. Y.
Lozier, William S., 10 Gibbs St., Rochester, N. Y.
Lund, Nels B., The Dorr Company, Inc., 370 Lexington Ave., New York, N. Y.
Luther, L. L., 46 No. Ocean Ave., Freeport, N. Y.
Lynch, Daniel E., Jr., Coney Island Sewage Plant, Ave. Z and Knapp St., Brooklyn, N. Y.
Lynch, James T., 86 Genesee St., Auburn, N. Y.
McBreen, Charles, Orangeburg, N. Y.
McCarthy, Justin J., 69 School St., Arlington, Mass.
McClelland, Ephraim, P.O. Box 377, Nanuet, N. Y.
McDonald, Michael D., N. Y. State Dept. of Public Health, 65 Court St., Buffalo, N. Y.
McDonald, Roland G., 409 Madison St., E. Rochester, N. Y.
McInerney, Gerald J., 544 South Main St., Elmira, N. Y.
McKay, Cornelius R., 34 Lincoln Road, Hempstead, N. Y.
McKeeman, Edwin C., 154 Colonial Ave., Freeport, N. Y.
McLaughlin, Carroll W., 266 Fulton Ave., Hempstead, N. Y.
MacCallum, C., 12 Reid Ave., Port Washington, N. Y.
MacCallum, Percy C., 120 Mineola Blvd., Mineola, N. Y.
MacCrea, J. M., 153 Oakland St., Syracuse, N. Y.
MacVenn, Melville J., 1625 35th St., Brooklyn, N. Y.
Magee, George W., Hudson River State Hospital, Pougheepsie, N. Y.
Mallory, Edward B., 169 East Clinton Ave., Tenafly, N. J.
Manahan, Patrick, Supt. of Sewage Disposal Works, Briarcliff Manor, N. Y.
Marrs, Paul, Box 87, Commack, N. Y.
Marshall, E. A., 167 Lafayette Ave., Geneva, N. Y.
Marshall, W. B., 1419 East Albion St., Apt. No. 9, Milwaukee, Wis.
Martin, Alexander G.. 36 Kinsy Ave, Kenmore, N. Y.
Martin, James T., 275 E. Gunhill Road, New York, N. Y.
Martin, Warren S., 42–09 206th St., Bayside, N. Y.
Maxwell, W. E., P.O. Box 92, Schenectady, N. Y.
Mendelsohn, I. W., 3875 Walde Ave., Bronx, N. Y.
Mercier, Julian J., 74–15 35th Ave., Jackson Heights, N. Y.
Michaels, John, Div. of Sewers, Queens Subway Bldg., Long Island City, N. Y.
Miller, David G., 840 Main St., Peekskill, N. Y.

Miller, Fred M., 30 Chestnut St., Glen Cove, N. Y.
Milliken, Harold E., Plant Opr., 32½ Elm St., Auburn, N. Y.
Mitchell, Louis, College of Applied Science, Syracuse University, Syracuse, N. Y.
Moore, George W., 26 Culver Parkway, Rochester, N. Y.
Mowbray, George A., 31 Hobart Ave., Port Chester, N. Y.
Mulcahy, James P., 49 Forest Row, Great Neck, N. Y.
Multiplex Concrete Company, Inc., P.O. Box 85, East Orange, N. J.
Municipal Sanitary Service, Corp., 155 East 44th St., New York, N. Y.
Murphy, Orville, Northville, N. Y.
Nangle, Bernard, 132–50 114th St., Ozone Park, N. Y.
Nayman, Frank S., 110 Linwood Ave., Albion, N. Y.
Nesbit, George H., 67 Adams St., East Rockaway, N. Y.
Neves, Dr. Lourenco Baeta, Prof. da Universidade de Minas Geraesm, Rua Claudio Manoel, 1185, Bello Horizonte Minas Geraes, Brazil, S. A.
Nevitt, I. H., 1091 Eastern Ave., Toronto, Ont., Canada.
Nielsen, A. F., 120 Broadway, New York, N. Y.
Nussbaumer, Newell L., 327 Franklin St., Buffalo, N. Y.
O'Brien, Earl F., 155 Fernwood Ave., Syracuse, N. Y.
O'Brien, James E., 31 Linden St., Schenectady, N. Y.
O'Brien, Stephen J., New Paltz, N. Y.
Ockershausen, Richard W., General Chemical Co., 40 Rector St., New York, N. Y.
O'Connor, William F., Jr., 14 Bayley Ave., Yonkers, N. Y.
Ogden, Henry N., Cornell University, Ithaca, N. Y.
Okun, W. H., 125 Worth St., New York, N. Y.
O'Leary, William A., 2728 Hendrick Hudson Parkway, Apt. B-66, Bronx, N. Y.
Orcutt, D. J., Electro Bleaching Gas Co., 60 E. 42d St., New York, N. Y.
Otto, Louis L., Sales Engr., 64 Lake St., Perry, N. Y.
Owen, Mark, Supt. Pub. Wks., 7752 Kentucky Ave., Dearborn, Michigan.
Parker, Charles F., Mallison, So. Windham, Maine.
Parry, John H., 8 Flagg St., Whitesboro, N. Y.
Paul, Lewis G., Hamburg, N. Y.
Peck, Lawrence J., Box 387, Delmar, N. Y.
Perrine, J. Franklin, Hunterspoint Ave., Borough Hall, Long Island City, N. Y.
Phelps, E. B., Prof., 630 West 168th St., New York, N. Y.
Phelps, E. K., 322 Fairmount Road, Ridgewood, N. J.
Phillips, H. N., 140 St. Andrews Lane, Glen Cove, N. Y.
Pineus, Sol, 4457 Waldo Ave., Bronx, N. Y.
Pinkney, Glenn E., 40 South Ave., Webster, N. Y.
Pitkin, Ward H., 70 Bay Drive Harbour Green, Massapequa, N. Y.
Pittsburg Equitable Meter, 400 N. Lexington Ave., Pittsburgh, Penna.
Pohl, C. A., 39 Cortland St., New York, N. Y.
Polakov, Nicholas N., N. Y. C. Dept. of Sanitation, 45 Lafayette St., Room 808, New York, N. Y.
Pollock, John M., Port Washington Sewer Comm., Port Washington, N. Y.
Potter, Alexander, 50 Church St., New York, N. Y.
Potts, Clyde, 30 Church St., New York, N. Y.
Powell, A. R., Koppers Research Corp., Kopper Bldg., Pittsburgh, Penna.
Powell, W. B., City Hall, Long Beach, N. Y.
Powers, Leo, P.O. Box 101, Brentwood, N. Y.
Provost, Andrew J., Jr., Darien, Conn.
Purdie, David J., Room 904, 20 Vesey St., New York, N. Y.
Rabbage, John B., 413 E. 8th St., Brooklyn, N. Y.
Raisch, William, 6945 Manse St., Forest Hills, N. Y.
Randall, Thomas D., 760–56th St., Brooklyn, N. Y.
Rashbach, D. Bennett, 502 West German St., Herkimer, N. Y.
Rath, Henry M., 50 West 9th St., New York, N. Y.
Reardon, Joseph F., Westside Ave., Garnersville, N. Y.
Rehler, Joseph E., 111 Monroe Terrace, Olean, N. Y.
Reisert, Michael J., 488 Oakland Ave., Cedarhurst, N. Y.
Rice, Lawrence H., 2161 Lubont Ave., New York, N. Y.
Rickard, Grover E., No. 11 City Hall, City Water Works, Burlington, Vermont.
Riddick, Thomas M., 369 East 149th St., New York, N. Y.
Riedel, John C., 505 Macon St., Brooklyn, N. Y.
Riley, Harley M., N. Y. State Health Dept., Room 709 Press Bldg., Binghamton, N. Y.

Roberts, C. R., Dr., 524 West 57th St.. New York, N. Y.
Roberts, Jack, 515 Dorlands Ave., Toronto, Ontario, Canada.
Robinson Clay Products Co., The, c/o A. T. Case, Empire State Bldg., New York, N. Y.
Robinson, George L., 5621 Grand Central Terminal, New York, N. Y.
Rocco, John, 20 Queen St., Freeport, N. Y.
Rock, Harold F., 46 Petrova Ave., Saranac Lake, N. Y.
Rogers, Allan H., 110 Seventh St., Garden City, N. Y.
Ruck, Carl F., Port Jefferson Station, N. Y.
Ryan, J. Samuel, 99 Olean St., Bolivar, N. Y.
Ryan, Wm. A., 202 Wimbledon Road, Rochester, N. Y.
Ryon, Henry, State Dept. of Public Works, Albany, N. Y.
Salle, Anthony, 81 Buffalo Ave., Long Beach, N. Y.
Salvato, Joseph, 6858 76th St., Middle Village, N. Y.
Sammis, L. A., P.O. Box 96, East Northport, N. Y.
Samson, Channel, 102 Parker Blvd., Kenmore, N. Y.
Sanborn, J. F., 30 Church St., New York, N. Y.
Saron, Fred E., 1749 Albany Ave., Brooklyn, N. Y.
Savage, Edward, 120 Broadway, New York, N. Y.
Saville, Thorndike Prof., Hydraulic and Sanitary Engineering, Box 65, New York University, University Heights, N. Y.
Schad, Fred, Bio-Reduction Corp., Davidson, N. C.
Schaefer, Edward J., 111–21 125th St., Ozone Park, N. Y.
Scherer, Paul, 761 E. 51st St., Brooklyn, N. Y.
Schmidt, William F., 53 Pierce St., Concord, Staten Island, N. Y.
Schreiner, W. R., c/o Dr. Burke Diefendorf, 412 Rogers Bldg., Glens Falls, N. Y.
Scott, Rossiter S., 112 Park Ave., New York, N. Y.
Scott, Roy D., State Hospital, Central Islip, N. Y.
Scott, Walter M., 145 South Third Ave., Mount Vernon, N. Y.
Scudder, Aubrey P., 80 Hamilton St., Rockville Centre, N. Y.
Seifert, William P., 77 Highview Ave., Tuckahoe, N. Y.
Seitz, Cecil, 427 City Hall, Buffalo, N. Y.
Shaw, D. J., 69 South Oxford St. (Times Plaza Sta.), Brooklyn, N. Y.
Sheppard, Frederick, 24 West 40th St., New York, N. Y.
Shockley, Homer G., 7004 Colonial Road, Brooklyn, N. Y.
Siegmann, Jr., Christian, 87 Thorne Ave., Hempstead, N. Y.
Sigworth, E. A., 48 Minell Place, Teaneck, N. J.
Simplex Valve and Meter Co., 342 Madison Ave., New York, N. Y.
Skinner, J. F., 3333 West 4th St., Los Angeles, Calif.
Slocum, Adelbert I., 515 Beach 68th St., Arverne, N. Y.
Smith, E. A. Cappelen, 120 Broadway, New York, N. Y.
Smith, Harold, 143 North Long Beach Road, Rockeville Centre, N. Y.
Smith, John J., 41–19 95th St., Elmhurst, N. Y.
Smith, L. R., 4 Pine St., Canton, N. Y.
Snyder, N. S., 331 Ellicott Square, Buffalo, N. Y.
Snow, Willis James, 16 Friendship St., New London, Conn.
Solomon, G. R., 257 Broadway, Troy, N. Y.
Solvay Sales Corp., Att: Mr. C. Grossman, 40 Rector St., New York, N. Y.
Southard, Clarence W., 68 Yorktown St., Rockville Centre, N. Y.
Sparr, A. E., 297 Ocean Ave., Brooklyn, N. Y.
Speirs, George W., 115–91 223d St., St. Albans, N. Y.
Spry, Fred J., Lincoln Hall, Cornell University, Ithaca, N. Y.
Stache, Paul, Box 339, Kings Park, L. I., N. Y.
Stalbird, James A., State Engr., Paul Smith Bldg., Saranac Lake, N. Y.
Stanley, Wm. E., Engr., School of Civil Engr., Cornell University, Ithaca, N. Y.
Steffensen, S. W., 125 Worth St., Room 821, New York, N. Y.
Stepanek, Chas. H. B., 506 E. 19th St., New York, N. Y.
Stepsis, John S., Central Islip State Hospital, Central Islip, N. Y.
Sterns, Edward A., 207 Long Ave., Hamburg, N. Y.
Stilson, Alden E., c/o Morse, Boulger Destructor Co., 202 E. 44th St., New York, N. Y.
Strait, Ernest C., 5 Brandreth St., Ossining, N. Y.
Streander, Philip T., 11 W. 42d St., New York, N. Y.

Strowbridge, John C., Supt. of Water and Sewers, Dundee, N. Y.
Stuart, Fred E., 230 Park Ave., New York, N. Y.
Summers, George J., 502 City Hall, Buffalo, N. Y.
Summers, Richard E. J., Pres., Sanitation Engineers and Constructors, Inc., 52 Vanderbilt Ave., New York, N. Y.
Sutherland, Henry M., 242 So. Grove St., Freeport, L. I., N. Y.
Sweeney, R. C., 217 Lark St., Albany, N. Y.
Sweeney, Willard G., 36 Grove Place, Babylon, N. Y.
Sylvester, William L., 54 Lafayette St., New York, N. Y.
Symons, G. E., Bird Island Laboratory, Buffalo, N. Y.
Taggart, Robert S., 268 Guy Park Ave., Amsterdam, N. Y.
Taylor, Henry W., 11 Park Place, New York, N. Y.
Taylor, Warren G., Prof., 38 Union Ave., Schenectady, N. Y.
Terhoeven, G. E., 295 Richmond Ave., Buffalo, N. Y.
Tetzlaff, Frank, Apartado 1244, Caracas, Venezuela, So. America.
Thomas, Howard S., 31 Exchange St., Rochester, N. Y.
Thomson, F. N., 10 Hopper St., Utica, N. Y.
Thornton, Edward, Box 273, Katonah, N. Y.
Thrasher, William E., 22 Halstead Ave., Mamaroneck, N. Y.
Tiedeman, W. D., Div. of Sanitation, State Dept. of Health, Albany, N. Y.
Timmers, Walter W., State Dept. of Public Works, Div. of Engineering, State Office Bldg., Albany, N. Y.
Tobin, James V., 26 Melroy Ave., Lackawanna, N. Y.
Tolman, S. L., c/o Jeffrey Mfg. Co., 1st Ave. and 4th St., Columbus, Ohio.
Trohn's Supplies, Inc., 201–203 Hoyt Ave., Mamaroneck, N. Y.
Van Denburg, J. W., 312 Mamaroneck Ave., White Plains, N. Y.
Van Deusen, E. J., 21 Pearl St., Malone, N. Y.
Vardon, Rolland F., 25 W. 71st St., New York, N. Y.
Velz, C. J., 327 North Ave., Fanwood, N. J.
Voorhis, Chester E., 253 Sunrise Highway,, Rockville Centre, N. Y.
Vrooman, Morrell, 10 N. Main St., Gloversville, N. Y.
Waag, Joseph P., 1406 Crossbay Blvd., Broad Channel, N. Y.
Wagenhals, H. H., 305 Herald Bldg., Syracuse, N. Y.
Wagner, Edward P., 55 West 42d St., New York, N. Y.
Wailes Dove Hermiston Corp., Att: Mr. M. F. Abrams, 17 Battery Place, New York, N. Y.
Walker, Allan P., 2262 Niagara Ave., Niagara Falls, N. Y.
Walker, Chas. L., 201 Fairmont Ave., Ithaca, N. Y.
Walker, W. J. D., 304 S. Collier St., Centralia, Mo.
Warde, John S., 50 Church St., New York, N. Y.
Watkins, William W., 130 East St., Oneonta, N. Y.
Watson, Carl H., 10 Cutter Mill Road, Great Neck, N. Y.
Watson, George L., 11 West 42d St., New York, N. Y.
Welsch, W. Frederick, 159 St. Pauls Road, N., Hampstead, N. Y.
Westcott, Arthur, Inst. for Male Defective Delinquents, Napanoch, N. Y.
Weston Company, L. A., Dean St., Adams, Mass.
Wheeler, Robert C., 36 State St., Albany, N. Y.
Wigley, Chester G., 3108 Atlantic Ave., Atlantic City, N. J.
Willcomb, George E., 12 South Lyons Ave., Menands, N. Y.
Williams, R. L., c/o Guggenheim Bros., Lab., 202d St. and 10th Ave., New York, N. Y.
Wilson, Jr., John A., Highwood Ave., Tenafly, N. J.
Wing, F. K., 1314 Prudential Bldg., Buffalo, N. Y.
Winslow, George W., 61 Keene Ave., Floral Park, N. Y.
Wiseman, Eugene R., 321 Seventh Ave., N., Troy, N. Y.
Witt, Jr., Frederick P., 145 Horton Highway, Mineola, N. Y.
Wood, Herbert M., 117 W. Sunrise Highway, Freeport, N. Y.
Woodhull, Charles R., 37 North St., Newburgh, N. Y.
Worthington Pump and Machinery Corp., Att: Mr. H. J. Meeker, Mgr. Sew. Div., Harrison, N. J.
Wyckoff, Charles R., 1239 New York Post Road, Scarsdale, N. Y.

Yatteau, George A., 1000 Winton Road N., Rochester, N. Y.
Young, W. W., Westchester Co. Sanitary Sewer Comm., County Office Bldg., White Plains, N. Y.
Yuan Hsi Djang, c/o Yuan-Mei Djang, China Foundation for the Promotion of Education and Culture, 22 Nan Chang Chick, Peiping, China.
Zack, Samuel I., c/o Filtration Equipment Corp., 10 E. 40th St., New York, N. Y.
Zeigler, Frederick G., 95 Stratford Ave., White Plains, N. Y.
Zuppinger, William, Blasdell, N. Y.

North Carolina Sewage Works Association

A. R. Hollett, *Secretary*, Dept. of San. Engineering, University of North Carolina, Chapel Hill, N. C.

Abell, D. S., Asst. Engr., R.F.D. 2, Old Fayetteville Rd., Raleigh, N. C.
Bain, Ernest B., 120 New Bern Ave., Raleigh, N. C.
Baity, H. G., Prof., Sanitary and Municipal Engineering, University of North Carolina, Chapel Hill, N. C.
Beggs, M. D., Worthington Gammon Meter Co., Box 4115, Elizabeth Station, Charlotte, N. C.
Benton, L. J., Supt. Water and Light Dept., Fremont, N. C.
Booker, Warren H., Director, Division of Sanitation, State Board of Health, Raleigh, N. C.
Burchard, Edwin D., District Engr., U. S. Geo. Survey, 220 Post Office Bldg., Asheville, N. C.
Burns, I. M., Supt. Water and Light Dept., Cherryville, N. C.
Chamblee, J. V., Supt. Public Utilities, Selma, N. C.
Clapp, Milton, Jr., Chemist, Sewage Disposal Plant, c/o City Water Works, Charlotte, N. C.
Cowing, V. J., Associate Engineer, P.W.A., Chapel Hill, N. C.
Davidson, Geo. T., Supt. Waterworks and Sewers, Mooresville, N. C.
Davis, H. F., Dist. Mgr., Wallace and Tiernan Co., Inc., 1720 Beverly Drive, Charlotte, N. C.
Doane, Norman D., 831 E. Morehead St., Charlotte, N. C.
Doggett, F. G., Disposal Plant, Mt. Airy, N. C.
Douglas, D. C., Merrimac Chemical Co., 1014 Johnston Bldg., Charlotte, N. C.
Durham Water Department, Durham, N. C.
Ebert, R. E., Chemist, Municipal Sewage Treatment Works, Winston-Salem, N. C.
English, Jas. A., City Engineer and Supt. Waterworks, Salisbury, N. C.
Evans, Wm. J., Filter Plant Operator, Box 819, Oxford, N. C.
Fisher, L. A., Board of Water and Light Comm., Box 188, Concord, N. C.
Franklin, W. M., Box 3162, Dilworth Sta., Charlotte, N. C.
Frisk, Paul W., Chemical Engr., Chief Chemical Laboratory, American Enka Corp., Box 45, Enka, N. C.
Furr, W. L., City Engineer, Concord, N. C.
Geyer, John C., Latrobe Hall, Johns Hopkins University, Baltimore, Md.
Godfroy, F. G., Supt. Water and Light Plant, New Bern, N. C.
Greenlee, J. L., Municipal Water Dept., Charlotte, N. C.
Grinnell Company, Inc., The, 1431 W. Morehead St., Charlotte, N. C.
Hall, W. H., Prof. Civil Engineering, Duke University, Durham, N. C.
Hamilton, S. C., Contracting Engineer, Chicago Bridge and Iron Works, Box 672, Birmingham, Ala.
Harkins, J. C., Supt., Roanoke Rapids Sanitary Dist., Roanake Rapids, N. C.
Henderlite, J. H., City Chemist, Gastonia, N. C.
Heyward, T. C., Mech. and Elec. Engineer, 1408 Independent Bldg., Charlotte, N. C.
Hickory, City of, Hickory, N. C.
Hill, Jr., R. F., Asst. Engr., North Carolina State Board of Health, Raleigh, N. C.
Holding, Willis, City Chemist, Raleigh, N. C.
Hollett, A. R., Instr. in Civil Engineering, University of North Carolina, Box 281, Chapel Hill, N. C.
Jarrett, J. M., State Board of Health, Raleigh, N. C.
Jenkins, W. O., Supt. Water Dept., Leaksville, N. C.
Kearney, E. W., 408 W. Union St., Morganton, N. C.
Kellogg, James W., Bact. and Chemist, State Lab. of Hygiene, Raleigh, N. C.
Lampley, J. H., Mgr., Board of Water Commissioners, Hendersonville, N. C.

Lassiter, L. I., Sanitary Engr., Consolidated Board of Health, Wilmington, N. C.
Lee, W. S., W. S. Lee Engineering Corp., Power Bldg., Charlotte, N. C.
Lybrook, W. M., Civil Engineer, 2319 Lawndale Drive, Greensboro, N. C.
Lyon, A. S., Supt. of Public Works, Rocky Mount, N. C.
McKimmon, W. S., State Board of Health, Raleigh, N. C.
McLeod, J. A., 2201 Benbow Road, Greensboro, N. C.
McMillian, R. S., Supt. Water Dept., Raeford, N. C.
Magee, W. G., Supt., Water and Light Dept., Box 452, Morehead City, N. C.
Martin, J. C., Supt., Municipal Light and Water Dept., Tarboro, N. C.
Maxwell, Joseph M., 4966 Woodland Ave., Cleveland, Ohio.
Meredith, E. P., Supt. Water Works, Washington, N. C.
Merritt, Will D., Supt. Water Dept. and City Engineer, Mount Airy, N. C.
Michie, John C., Supt. Water Dept., Durham. N. C.
Miles, H. J., Textile Foundation, 1000 N. Elm St., Greensboro, N. C.
Moore, Geo. S., Supt. Water and Light Dept., Albemarle, N. C.
Moss, E. H., Supt. of Plants, High Point, N. C.
Nance, E. L., Route No. 3, Charlotte, N. C.
Olsen, W. C., Consulting Engineer, Raleigh, N. C.
Parks, W. J., Supt. Water Sheds, Asheville, Swannanoa, N. C.
Perkins, J. L., Supt. Municipal Water and Light Dept., High Point, N. C.
Philips, R. S., 319 E. Trinity Ave., Durham, N. C.
Piatt, Wm. M., Consulting Engineer, Durham, N. C.
Pollock, John M., Supt. Sewage Treatment, Spindale, N. C.
Ponte, J. Raf Martinez, Dr., Norte 14 No. 139, Caracas, Venezuela, So. America.
Potter, R. M., Hertford, N. C.
Rhyne, C. E., Supt. Water Works, Gastonia, N. C.
Seaman, Henry, Champion Fibre Co., Canton, N. C.
Smedberg, C. W., 315 Woodbine St., Greensboro, N. C.
Swartz, Martin, Supt. Water and Light Comm., Greenville, N. C.
Thomas, E. R., Supt. Municipal Water Dept., Burlington, N. C.
Thomas, R. Allen, Comm. Public Works, Winston-Salem, N. C.
Thompson, H. E., Supt. of Filtration, University of North Carolina, Chapel Hill, N. C.
Thompson, Meredith, Dr., Asst. Engr., State Board of Health, Raleigh, N. C.
Thorpe, D. W., Hamlet Water Co., Hamlet, N. C.
Trice, M. F., Asst. Engr. State Board of Health, Raleigh, N. C.
True, Albert O., Sanitary Engr. Denim Branch, Proximity Mfg. Co., Greensboro, N. C.
Tull, E. R., Supt. Municipal Water Plant, Rockingham, N. C.
Vest, W. E., Supt. Water Works, Charlotte, N. C.
Warrenton Water Co., Warrenton, N. C.
Weathers, J. L., Supt., Public Works Comm., Fayetteville, N. C.
Williams, C. B., Supt. Water and Light, Lexington, N. C.
Williams, Macon W., Lenoir, N. C.
Witty, T. E., Water Dept., Thomasville, N. C.
Yow, W. E., Supt. Water Dept., Asheboro, N. C.

Ohio Sewage Works Conference Group

Frank W. Jones, *Secretary-Treasurer*, 1140 Leader Bldg., Cleveland, Ohio

Allton, Robert A., City Hall, Columbus, Ohio.
Andrews, Carl S., 1417 Regent, Cincinnati, Ohio.
Arnold, Walter, 11214 Parklawn, Cleveland, Ohio.
Avery, J. W., 1188 Virginia Ave., Lakewood, Ohio.
Backherms, A. B., 3438 Sherel Circle, Cincinnati, Ohio.
Backherms, Louis E., 549 Court House, Cincinnati, Ohio.
Bahlmann, Clarence, Water Purification Supervisor, Cincinnati Filtration Plant, California, Ohio.
Barnes, George E., Prof., Case School of Applied Science, Cleveland, Ohio.
Barstow, E. D., Barstow and LeFeber, Inc., 31 N. Summit St., Akron, Ohio.

Barton, Ben H., 207 Locust St., Findlay, Ohio.
Bartow, Leslie W., 211 East Hudson St., Columbus, Ohio.
Behnke, Geo. C., 400 E. College St., Oberlin, Ohio.
Blanchard, H. E., c/o A. H. Fretter, 603 S. Broadway, Medina, Ohio.
Bonney, O., Sewerage Relief Engineer, City Hall, Columbus, Ohio.
Bradshaw, W. L., Sanitary Engineering Division, The Jeffrey Mfg. Co., Columbus, Ohio.
Britt, C. E., 505 South Maple St., Bowling Green, Ohio.
Broestl, Andrew J., 1283 Hird Ave., Lakewood, Ohio.
Browne, Floyd G., Box 134, Marion, Ohio.
Bryant, C. T., Supt., Sewage Treatment Works, Pleasant and Dayton Aves., Springfield, Ohio.
Burger, A. A., Engr., 3306 Elsmere Road, Shaker Heights, Cleveland, Ohio.
Burnett, R. E., Box 134, Marion, Ohio.
Cameron, A. B., Hotel Otsego, Jackson, Mich.
Case School of Applied Science, Att: Prof. George E. Barnes, Dept. of Civil Engineering, Euclid Ave., opposite Wade Park, Cleveland, Ohio.
Clover, I. N., 28 Byers Ave., Akron, Ohio.
Collier, James R., 217 Harwood St., Elyria, Ohio.
Corbin, Lee, Supt. Water and Sewers, Barnesville, Ohio.
Craun, J. M., 355 Hippodrome Annex, Cleveland, Ohio.
Critser, W. H., 201 Church Place, Mt. Lebanon, Penna.
Cummins, Walter, 2021 Mason St., Toledo, Ohio.
Dick, George C., Supt. Berea College, Berea, Ky.
Dittoe, W. H., Chief Engr., Mahoning Valley San. Dist., 901 City Bank Bldg., Youngstown, Ohio.
Dixon, G. Gale, 301 Arcade Bldg., Harrisburg, Penna.
Duerr, A., 233 Westwood Ave., Orrville, Ohio.
Eagle, George H., 1367 Meadow Road, Columbus, Ohio.
Ellms, J. W., 1310 West 112th St., Cleveland, Ohio.
English, C. C., Banes, Cuba.
Evans, E. B., Cincinnati Water Works, California, Ohio.
Fisher, F. P., Wallace and Tiernan Co., 811 Perry-Payne Bldg., Cleveland, Ohio.
Flower, G. E., 1301 West 110th St., Cleveland, Ohio.
Ford, Curry E., Consolidated Carbon Sales Div., National Carbon Co., Inc., Cleveland, Ohio.
Gray, D. M., Louisville Cement Co., Louisville, Ky.
Griffin, D. P., 133 Dawson Ave., Mansfield, Ohio.
Growdon, Howard C., 2519 Ritchie St., Portsmouth, Ohio.
Hall, G. Albro, 546 Pearl St., Marion, Ohio.
Harroun, F. E., 711 Chitty Ave., Akron, Ohio.
Hatch, B. F., State Health Department, Pure Oil Building, Columbus, Ohio.
Havens, William L., 1140 Leader Bldg., Cleveland, Ohio.
Henkelman, W. W., Beilstein Bldg., Sandusky, Ohio.
Hess, A. E., Supt. of Water and Sewage Plants, Alliance, Ohio.
Hommon, Charles C., 140 22nd St., N.W., Canton, Ohio.
Hoover, C. B., 252 East 17th Ave., Columbus, Ohio.
Hopkins, William J., 1217 E. 80th St., Cleveland, Ohio.
Houser, C. S., 165 S. Paint St., Chillicothe, Ohio.
Hull, F. J., Box 887, Ashtabula Harbor, Ohio.
Jones, Frank Woodbury, 1140 Leader Bldg., Cleveland, Ohio.
Kimberly, A. E., 20 So. Third St., Columbus, Ohio.
Kline, H. S., 5 Palmer St., Apt. 21, Dayton, Ohio.
Knox, W. H., Asst. Engr., State Dept. of Health, Pure Oil Bldg., Columbus, Ohio.
Leach, Walter L., 1140 Leader Bldg., Cleveland, Ohio.
Lesher, Carl, 1140 Leader Bldg., Cleveland, Ohio.
Lockett, Paul F., 843 W. Main St., Newark, Ohio.
Lower, J. R., Chemist-in-Charge, Bucyrus Water Works, Bucyrus, Ohio.
McDill, Bruce M., State Dept. of Health, Pure Oil Bldg., Columbus, Ohio.
McGuire, C. D., 448 Clinton St., Columbus, Ohio.
McGuire, J. Q., Supt. of Filtration, State St. and Davis Ave., Columbus, Ohio.
MacDowell, R. F., 341 Chester-Twelfth Bldg., Cleveland, Ohio.
MacLachlan, Angus, 1740 East 12th St., Cleveland, Ohio.
Marsh, Royden E., Box 456, Windsor, Colo.
Marshall, L. A., Supt. of Filtration, Division Ave. Filtration Plant, West 32nd St. and Division Ave., Cleveland, Ohio.

Monroe, S. G., R.F.D. No. 7, Box 99, Akron, Ohio.
Morehouse, W. W., Director of Water Department, 308 U. B. Annex, Dayton, Ohio.
Moseley, Harry H., 1140 Leader Bldg., Cleveland, Ohio.
Nelson, Frederick G., 1231 Edison Bldg., Toledo, Ohio.
O'Brien, Walter S., Apt. 724 Miramar Apt. Hotel, 1301 15th St., N.W., Washington, D. C.
Pease, Maxfield, 4614 Prospect Ave., Cleveland, Ohio.
Purification Systems, Inc., Att: Charles H. Shook, Pres., 582 W. 2nd St., Dayton, Ohio.
Raffety, J. S., 3148 Lookout Ave., Cincinnati, Ohio.
Redrup, A. F., Park Hotel, Van Wert, Ohio.
Regester, Robert T., 401 Gittings Ave., Cedarcroft, Baltimore, Md.
Roth, R. F., Municipal Bldg., Oxford, Ohio.
Rupp, Daniel H., Water Department, City Hall, Topeka, Kansas.
Schaetzle, T. C., 502 Municipal Bldg., Akron, Ohio.
Scott, R. D., Chief Chemist, Division of Laboratories, State Dept. of Health, Columbus, Ohio.
Sheets, W. D., 2009 Floral Ave., Columbus, Ohio.
Smiley, Paul E., 324 Point View Ave., Dayton, Ohio.
Smith and Niles Co., A. H., The, 112 E. Woodruff Ave., Toledo, Ohio.
Smith, E. E., Supt. Water and Sewage, Lima, Ohio.
Stewart, F. D., Principal Asst. Engineer, State Dept. of Health, Pure Oil Bldg., Columbus, Ohio.
Sweeney, R. C., Division of Sanitation, State Dept. of Health, Albany, N. Y.
Tatlock, M. W., 911 Ferndale Ave., Dayton, Ohio.
Tolles, Frank C., 1140 Leader Bldg., Cleveland, Ohio.
Wahmhoff, John J., Supt. Sewage Treatment Works, 427 E. Harmon St., Delphos, Ohio.
Walker, C. C., 1826 W. 1st Ave., Columbus, Ohio.
Waring, F. H., Chief Engr., State Health Dept., c/o Pure Oil Bldg., Columbus, Ohio.
Weiger, Merl D., 3088 West 106th St., Cleveland, Ohio.
Wenger, J. H., 41 West Home St., Westerville, Ohio.
Wharton, Richard, 49 McOwen St., Dayton, Ohio.
Willis, Robert E., 411 N. North St., Washington, C. H., Ohio.
Wirts, J. J., Westerly Sewage Treatment Works, West 58th St. and Bulkley Blvd., Cleveland, Ohio.
Young, F. D., 1140 Leader Bldg., Cleveland, Ohio.

Oklahoma Water and Sewerage Conference

H. J. Darcey, *Secretary-Treasurer*, Dept. of Public Health, Oklahoma City, Okla.

Stapley, E. R., Prof. of Civil Engineering,
A. & M. College, Stillwater, Okla.

Pacific Northwest Sewage Works Association

Fred. Merryfield, *Secretary*, Civil Engineering Dept., Oregon State College, Corvallis, Ore.

Adams, John M., City Engr., Bellingham, Wash.
Bjork, G. E., 3995 N. E. 40th Ave., Portland, Ore.
Burns, James R., 132 East Maple, Hillsboro, Ore.
Butler, A. D., City Engr., Spokane, Wash.
Campbell, Maxwellton S., 1412 Smith Tower, Seattle, Wash.
Charlton, David, Dr., 705 Stevens Bldg., Portland, Ore.
Chase, E. French, Sanitary Engr., Seattle, Wash.
Cunningham, John W., Spalding Bldg., Portland, Ore.
Davis, Edmund I., Civil Engr., 707 Fifth St., Oregon City, Ore.
Everts, C. M., Jr., Acting State San. Engr., 816 Oregon Bldg., Portland, Ore.
Forsbeck, C. D., City Engr., Tacoma, Wash.
Franks, R. W., Asst. State Sanitary Engr., Oregon State Board of Health, Oregon Bldg., Portland, Ore.
Green, Carl E., 816 Oregon Bldg., Portland, Ore.

Hall, G. D., 416 A. E. Larson Bldg., Yakima, Wash.
Harris, Roy M., 1412 Smith Tower, Seattle, Wash.
Harrison, Verne, 404 Engineer Hall, Ames, Iowa.
Hill, K. V., c/o Greeley and Hansen, 6 N. Michigan Ave., Chicago, Ill.
Hockley, C. C., 508 Foiling Bldg., Portland, Ore.
Hooker, Albert H., Jr., Hooker Electro-Chemical Co., Tacoma, Wash.
Irwin, G. M., City Engr. and Water Commissioner, Victoria, British Columbia, Can.
Jackson, T. B., Pres. and Gen. Mgr., Boise Water Corp., 623 Idaho St., Boise, Idaho.
Koon, Ray E., Spalding Bldg., Portland, Ore.
Merryfield, Fred, Civil Engineering Dept., Oregon State College, Corvallis, Ore.
Mitchell, George, Wallace and Tiernan Co., Inc., 917 Terminal Sales Bldg., Seattle, Wash.
National Tank and Pipe Co., Kenton, Station, Portland, Ore.
Philips, C. J., City Hall, Puyallup, Wash.
Rogers, H. M., City Engr., City Hall, Salem, Ore.
Seufer, Paul E., Asst. Public Health Engineer, State Dept. of Health, Smith Tower, Seattle, Wash.
Shera, Bryan, Engineer for the Pennsylvania Salt Mfg. Co., Tacoma, Wash.
Signor, C. V., City Engr., Grants Pass, Ore.
Smith, C. H., Sewer Engr., City Hall, Portland, Ore.
Snyder, M. K., Prof., Civil Engineering Dept., Washington State College, Pullman, Wash.
Stockman, L. R., Consulting Engr., Box 635, Baker, Ore.
Stockman, R. C., Green Gable Court, Terrell, Texas.
Turner, E. S., W. S. Turner and Co., Pacific Bldg., Portland, Ore.
Tyler, R. G., Dean, University of Washington, Seattle, Wash.
Van Horn, R. B., Prof., Executive Head, Dept. of Civil Engineering, University of Washington, Seattle, Wash.

Pennsylvania Sewage Works Association

L. D. Matter, *Secretary-Treasurer*, Room 217 Kirby Health Center, Wilkes-Barre, Pa.

Agar, C. C., Sr. Sanitary Engr., New York State Dept. of Health, Albany, N. Y.
Anderson, W. R., Borough Supt., 228 Market St., New Wilmington, Pa.
Armstrong, Paul A., Chemist, Pennsylvania Sanitary Water Bd., 824 Porter St., Easton, Pa.
Bailey, S. C., Danville State Hospital, Danville, Pa.
Baker, Michael, Jr., Borough Engineer, State College, Pa.
Baltz, Elmer E., Engineer in Charge of Pumping Stations, Township of Lower Merion, 75 East Lancaster Ave., Ardmore, Pa.
Barney, John J., Sewage Treatment Works, Byberry, Philadelphia, Pa., Torresdale P.O.
Barrick, M. J., Dist. Engr., 28 E. Third St., Williamsport, Pa.
Baum, H. J., City Engr., Altoona, Pa.
Beckett, R. C., State Sanitary Engineer, State Board of Health, Dover, Del.
Blunt, Harrison, Consulting Engineer, Palmerton Disposal Co., Palmerton, Pa.
Boardman, John, Sanitary and Hydraulic Engineer, 426 Walnut St., Philadelphia, Pa.
Boardman, Wm. Hunter, Jr. Civil Hyd. and San. Engineer, 426 Walnut St., Philadelphia, Pa.
Bogardus, Theodore S., Asst. City Engr., Meadville, Pa.
Boone, George H., Chief Opr., Sewage Treatment Plant, 713 Church St., Norristown, Pa.
Brown, Glenn V., Dr., 312 East Main St., Mechanicsburg, Pa.
Brumbaugh, W. Vernon, National Lime Assn., 927 Fifteenth St., N.W., Washington, D. C.
Buck Hill Falls Co., Att: Elliot Wells, Rep., Buck Hill Falls, Pa.
Bush, Bernard, Asst. Engr., Pa. Dept. of Health, Kirby Health Center, Wilkes-Barre, Pa.
Butler, City of, City Eng. (Rep.), Butler Pa., F. M. Harper, Rep.
Cameron, A. B., Supt., Hotel Otsego, Jackson, Mich.
Carpenter, Lewis V., New York University, University Heights, New York, N. Y.
Chambersburg, Boro of, J. Hase Mowrey, Rep., Public Utilities, Chambersburg, Pa.
Chase, E. Sherman, Metcalf and Eddy, Statler Bldg., Boston, Mass.
Chester, Campbell Davis and Bankson, 1050 Century Bldg., 103 7th St., Pittsburgh, Pa.
Clausen, Frank, Disposal Plant Operator, 243 Carre Ave., Essington, Pa.

Cleland, R. R., Dept. of Grounds and Buildings, Penn. State College, State College, Pa.
Clouser, L. H., Tennessee Valley Authority, Room 615, Union Bldg., Knoxville, Tenn.
Coy, Paul F., Sewage Treatment Plant, Meadville, Pa.
Craig, Robert H., Consulting Engr., Chamber of Commerce Bldg., Harrisburg, Pa.
Cunningham, H. L., Allentown State Hospital, Allentown, Pa.
Damon and Foster, Chester Pike and High St., Sharon Hill, Pa.
Daniels, F. E., Chief, 2115 N. Second St., Harrisburg, Pa.
Darby, W. A., The Dorr Company, 570 Lexington Ave., New York, N. Y.
Davis, E. Watson, Asst. Civil Engr., Room 506 S. Office Bldg., Harrisburg, Pa.
Dechant, Wm. H. and Sons, F. H. Dechant, Rep., 526 Franklin St., Reading, Pa.
Diefendorf, Fred. G., Supt., Box 124, Erie, Pa.
Eastburn, W. H., Rep., The Mathieson Alkali Works, Inc., Widener Bldg., Philadelphia, Pa.
Eckbert, Chester A., Borough Manager, Hanover, Pa.
Edgerley, Edward, City Engr., 343 N. West End Ave., Lancaster, Pa.
Eidemiller, Adam, Contractor, Greenburg, Pa.
Emerson, C. A., Jr., c/o George B. Gascoigne, Woolworth Bldg., New York, N. Y.
Emigh, William C., Coatesville, Pa.
Evans, David A., P.O. Box 862, Reading, Pa.
Fales, Almon L., Metcalf and Eddy, Statler Bldg., Boston, Mass.
Fick, Henry H., Water Works Engineer, Bureau of Engineering, Public Utility Comm., Harrisburg, Pa.
Fischer, Kermit K., 11 W. Durham St., Mt. Airy, Philadelphia, Pa.
Fleming, M. C., Engineer, Hardinge Co., Inc., York, Pa.
Freeburn, H., Suite 303, Keystone Bldg., Broad and Vine Sts., Philadelphia, Pa.
Friel, F. S., Albright and Friel, 1520 Locust St., Philadelphia, Pa.
Fulweiler, W. H., Chemical Engr., Room 1040, 1600 Arch St., Philadelphia, Pa.
Gascoigne, Geo. B., 1140 Leader Bldg., Cleveland, Ohio.
Gidley, H. K., c/o State Health Dept., Charleston, W. Va.
Gilbert, J. J., Sanitary Engr., 201 Wheatsheaf Lane, Abington, Pa.
Gill, Paul, 725 Chestnut St., Indiana, Pa.
Glace, I. M., 22 S. 22nd St., Harrisburg, Pa.
Gorman, William A., Penn. Dept. of Health, Harrisburg, Pa.
Grabowski, John J., 18 N. 4th St., Sharpsburg, Pa.
Grace, C. F., Polk State School, Polk, Pa.
Haddock, Fred. R., Chief Engineer, Roberts Filter Mfg. Co., Darby, Pa.
Hancock, H. R., City of Dover, Dover, Del.
Harris, J. F., Stroudsburg Septic Tank Co., 312 Main St., Stroudsburg, Pa.
Hartzell, E. F., Supt., Palmerton Disposal Co., Palmerton, Pa.
Harvey, J. R., Pa. Dept. of Health, 609 Trust Bldg., Meadville, Pa.
Haseltine, T. R., Sanitary Engineer, Butler, Pa.
Haywood, R. W., Jr., 315 Burke St., Easton, Pa.
Hedgepeth, L. L., Research Chemist, Pa., Salt Mfg. Company, 1000 Widener Bldg., Philadelphia, Pa.
Heister, Ralph M., 35 Vine St., Tamaqua, Pa.
Herr, H. N., 114 Java Ave., Hershey, Pa.
Hess, Joseph C., Jr., Chr. Sewer Comm.—Ambler Boro Council, 412 Tennis Ave., Ambler, Pa.
Hewitt, A. C., Chief Engineer, American Lime and Stone Co., Bellefonte, Pa.
Hill, Theo. C., Hill and Hill, Engineers, North East, Pa.
Hoak, Richard D., Pa. Dept. of Health, 506 S. Office Bldg., Harrisburg, Pa.
Hoffert, J. R., Pa. Dept. of Health, Harrisburg, Pa.
Hutton, H. S., Wallace and Tiernan Co., Inc., Newark, N. J.
Imbt, M. Russell, Sales Engr., Stroudsburg Septic Tank Co., 312 Main St., Stroudsburg, Pa.
Jenne, Lyle L., San. Engr., Bureau of Water, 819 City Hall Annex, Philadelphia, Pa.
Johnson, Earle P., Flannery Bldg., Pittsburgh, 13, Pa.
Johnson, Russell L., Sanitary Engr. County Health Dept., Coldwater, Mich.
Jones, Everett M., Sales Eng., Simplex Valve and Meter Co., 36 W. Pamona St., Philadelphia, Pa.
Jones, Frank Woodbury, c/o Geo. B. Gascoigne, Leader News Bldg., Cleveland, Ohio.
Kappe, S. E., 627 West Kingsley St., Philadelphia, Pa.
Kelsey, Walter, Lord and Burnham Co., Irvington-on-Hudson, N. Y.
Kinsel, H. L., 2439 Delaware, Buffalo, N. Y.
Kistler Leather Company, J. M. Seltzer, Chief Chemist, Rep., Lock Haven, Pa.

Kremer, Robert W., Penna. Dept. of Health, First National Bank Bldg., Greensburg, Pa.

Krumm, Harry J., City Chemist, Jefferson and Lawrence, Allentown, Pa.

Langford, L. L., Eastern Sales Mgr., Pacific Flush-Tank Co., 441 Lexington Ave., New York, N. Y.

Lauer, Chas. N., Supt. Sewage Disposal Plant, City Hall, York, Pa.

Leh, Willard, Asst. San Engr., Pa. Dept. of Health, 303 Keystone Bldg., Broad and Vine Sts., Philadelphia, Pa.

Leithiser, Elmer, Capt., Deputy Warden, New Eastern State Penitentiary, Graterford, Pa.

Link-Belt Company, Mr. M. B. Tark, Rep., Philadelphia, Pa.

Long, George S., Engineering Designing, 135 Borton Ave., Akron, Ohio.

Lubrecht, Frank S., Consulting Engineer, 310 Hazleton National Bank Bldg., Hazleton, Pa.

Luebert, A. G., Director, Streets and Public Imp., 126 S. 5th Ave., Coatesville, Pa.

Lutz, Howland C., Field Asst., Pa. Dept. of Health, Glen Rock, Pa.

McAdoo and Allen Welting Company, South Hellertown Ave., Quakertown, Pa.

Mansfield, M. G., Rep. Morris Knowles, Inc., 507 Westinghouse Bldg., Pittsburgh, Pa.

Manz, Erwin C., 585 E. Martin St., Roxborough, Philadelphia, Pa.

Matter, L. D., Dist. Eng., Pa. Dept. of Health, Kirby Health Center, Wilkes-Barre, Pa.

Mebus, Chas. F., 112 S. Easton Rd., Glenside, Pa.

Menantico Sand and Gravel Co., P.O. Box No. 65, Millville, N. J.

Merkel, Paul, Consulting Chemist, 1528 N. 11th St., Reading, Pa.

Miller, Paul E., 25 Maltbie Road, Midland Park, N. J.

Miller, Roy, Treatment Plant Opr., 1640 Lincoln Ave., Northampton, Pa.

Milligan, Francis B., 2314 Walnut St., Camp Hill, Pa.

Molitor, Paul, Sr., Consulting Operating Engr., Chatham, N. J.

Monroe, Lowell W., Borough Manager, City Bldg., Elwood City, Pa.

Montagna, S. D., Box 308, Cecil, Washington Co., Pa.

Moses, H. E., 1421 North Front St., Harrisburg, Pa.

Mowry, Robert B., Dist. Engineer, Wallace and Tiernan Co., Inc., 1505 Race St., Philadelphia, Pa.

Mulvihill, F. J., Hotel Harrington, Washington, D. C.

Nugent, Franklin J., 10 N. Greenwood St., New Castle, Pa.

Oberlander, Theodore F., 171 Union Blvd., Kitchener, Ontario, Can.

O'Donnell, R., 119 S. Atherton St., State College, Pa.

Olewiler, Grant M., Asst. Supt. of Health and Drainage, 75 East Lancaster Ave., Ardmore, Pa.

Oxenreider, Harry I., Sales Engr., Kaustine Co., Inc., 522 Court St., Reading, Pa.

Palmer, I. Charles, City-County Bldg., Room 423, Bureau of Sewers, Pittsburgh, Pa.

Payrow, Harry G., Rep. Asst. Prof. Sanitary Engineering, Dept. of Civil Engineering, Lehigh University, Bethlehem, Pa.

Pecker, Joseph S., Cons. Engr., 900 Victory Bldg., 1011 Chestnut St., Philadelphia, Pa.

Pfreimer, Harold, Pa. Dept. of Health, Harrisburg, Pa.

Reuning, Howard T., Engineering Dept., Elk Tanning Company, 330 Allenhurst Ave., Ridgway, Pa.

Rhoads, Edward J., Supt. of Sewage Treatment Plant, City of Lancaster, 531 Chester St., Lancaster, Pa.

Rice, C. L., Jr. Hydraulic Engr. with T.V.A., 511 Union Bldg., c/o T.V.A., Knoxville, Tenn.

Rice, John M., Cons. Eng., 2502 Grant Bldg., Pittsburgh, Pa.

Rice, T. P., Chemist, Pa. Dept. of Health, 1009 N. Canal St., Sharpsburg, Pa.

Roeller, R. S., Dist. Sales Mgr., Pa. Salt Mfg. Co., 1000 Widener Bldg., Philadelphia, Pa.

Roetman, E. T., 614 Third Ave., St. Albans, W. Va.

Rogers, D. Paul, Senior Chemist, State Health Dept., Harrisburg, Pa.

Rogers, H. L., Sewage Treatment Plant Operator, City of Easton, City Hall, Easton, Pa.

Rosengarten, W. E., Twp. Engr., 75 E. Lancaster Ave., Ardmore, Pa.

Rutter, Lee D., Supt. of Sewers, City Hall, Lebanon, Pa.

Schaut, George G., 1308 W. Ontario St., Philadelphia, Pa.

Scheffer, Louis K., 1013 Green St., Harrisburg, Pa.

Schnupp, Leonard J., Borough Bldg., Jeannette, Pa.

Searight, Geo. P., Borough Manager, Carlisle, Pa.

Shaw, George H., 450 Longfellow St., N.W., Washington, D. C.
Shertzer, J. H., City Engr., Lancaster, Pa.
Shields, James L., Engineer, Textile Machine Works, Wyomissing, Pa.
Showalter, Charles M., Laurelton St. Village, Laurelton, Pa.
Siebert, Christian L., Exec. Engineer, Sanitary Water Board, Pa. Dept. of Health, Harrisburg, Pa.
Smith, Merlin D., Sewage Plant Operator, Laurelton State Village, Laurelton, Pa.
Snelsire, William, Rep., Pa. Salt Mfg. Co., 641 Union Trust Bldg., Pittsburgh, Pa.
Speiden, H. W., Dept. of Civil Engineering, West Virginia University, Morgantown, W. Va.
Stevenson, W. L., 2214 No. 2nd St., Harrisburg, Pa.
Stewart, H. M., 35th and Allegheny Ave., Philadelphia, Pa.
Stone, Alvin F., Supv., City Sewage Disposal Plant, City Hall, Reading, Pa.
Swinehart, Eugene B., Chief Operator, Pottstown Boro Sewage Disp. Plant, 1133 South St., Pottstown, Pa.
Taylor, Floyd B., Jr. Asst. Sanitary Engr., 37 Grow Ave., Montrose, Pa.
Taylor, Henry W., Cons. Engineer, 11 Park Place, New York City.
Trebler, H. A., Chem. Engr., 1403 Eutaw Place, Baltimore, Md.
Trescott, Boyd, 230 E. Front St., Berwick, Pa.
Turner, Homer G., Director of Research for Anthracite Inst., School of Mineral Industries, Pa. State College, State College, Pa.
Tygert, C. B., Representative, Wallace & Tiernan Co., Inc., 208 Jackson Ave., Rutherford, N. J.
Umbenhauer, E. J., P.O. Box 333, 1920 Corpus Christi St., Laredo, Texas.
Wagner, Edwin B., Downington, Pa.
Wagner, Raymond F., Sr. San. Engr. Aid, Mass. Dept. of Health, 28 Gorham St., Cambridge, Mass.
Walker, Elton D., Pa. State College, Head, Dept. of Eng., State College, Pa.
Walker, Isaac S., Consulting Engr., 1208 Harrison St., Philadelphia, Pa.
Warren State Hospital, H. A. Otterson, Rep., Warren, Pa.
Watson, Harold Fieldwig, Engr., 519 E. Tulpehocken St., Philadelphia, Pa.
Watts, M. R., Chemist, Pa. Dept. of Health, 1009 N. Canal St., Sharpsburg, Pa.
Wayne Laboratories, The, 17 East Main St., Att: Mr. J. J. Shank, Waynesboro, Pa.
Welsford, H. R., 5523 Pulaski St., Philadelphia, Pa.
Wertz, C. F., Cons. Engr., 1522 Woolworth Bldg., New York.
Whitby, Steve, Culbert Whitby Co., Reps. Chicago Pump Co., 2019 Rittenhouse St., Middle City Station, Philadelphia, Pa.
Whitcomb, Leon R., Pardee Mfg. Co., 2402 Market St., Philadelphia, Pa.
White Haven Sanatorium, Att: Mr. R. A. Dodson, Rep., White Haven, Pa.
Wiest, Gordon J., Chemist, 41 Spencer Ave., Lancaster, Pa.
Williams, A. C., Township Engr., Haverford Township, Upper Darby P.O., Oakmont, Pa.
Williams, James C., Operator, Sewage Treatment Plant, Danville State Hospital, Danville, Pa.
Williams, Percy B., 709 No. Third St., Harrisburg, Pa.
Wilson, E. M., Pa. Salt Mfg. Co., 1000 Widener Bldg., Philadelphia, Pa.
Yerkes, Milton R., Engineer, Radnor Twp., Wayne, Pa.
Yimm, Leo J., Chemist, 1009 N. Canal St., Sharpsburg, Pa.
Young, C. H., Dist. Engr., Pa. Dept. of Health, 608–09 Crawford County Trust Bldg., Meadville, Pa.
Young, F. D., Cons. Engr., 1140 Leader Bldg., Cleveland, Ohio.

Rocky Mountain Sewage Works Association

Dana E. Kepner, *Secretary*, 1921 Blake St., Denver, Colo.

Blackman, A. T., Supt. Water and Sewers, City Hall, Sterling, Colo.
Blizzard, George, Supt. of Water and Sewers, City Hall, Lamar, Colo.
Boyer, F. H., Manufacturer's Agent, 1925 Blake St., Denver, Colo.
Davis, Charles A., City San. Engr., City and County Bldg., Denver, Colo.
Denver Public Library, Att: Mr. F. M. Veatch, Technical Dept., Civic Center, Denver, Colo.
Dorr Company, Inc., The, Att: E. C. Reybold, Secy. Rep., 1009 17th St., Denver, Colo.
Downing, Roderick L., Assoc. Prof. of Civil Engineering, University of Colorado, 983 14th St., Boulder, Colo.

Elliot, S. F., City Engineer, City Hall, Pueblo, Colo.
Gelder, R. W., Consulting Engr., Greeley, Colo.
Gross, Dwight D., Chief Engr., Bd. of Water Commissioners, City and County Bldg., Denver, Colo.
Hendrie and Bolthoff Mfg. and Supply Co., Capt. J. S. Smith, Vice-Pres., Rep., 1635 17th St., Denver, Colo.
Howe, Ben V., State Sanitary Engineering, 428 State Office Bldg., Denver, Colo.
Howell, Eugene, Asst. State San. Engr., 428 State Office Bldg., Denver, Colo.
Kepner, Dana E., 1921 Blake St., Denver, Colo.
Lock Joint Pipe Co., Att: Mr. Wm. B. Freeman, Branch Mgr., 1716 California St., Denver, Colo.
McClintock, H. C., City Mgr., Boulder, Colo.
McCullough, Jay W., 215 Majestic Bldg., Denver, Colo.
McQuaid, Dan J., Cons. Engr., 614 Cooper Bldg., Denver, Colo.
Moodey, T. B., City Engr., City Hall, Greeley, Colo.
New Mexico Bureau of Public Health, Att: Mr. Paul S. Fox, San., Engr., P.O. Box 711, Santa Fe, New Mexico.
Osborn, L. C., City Engineer, Loveland, Colo.
Pacific Flush Tank Co., 4241 Ravenswood Ave., Chicago, Ill.
Rust, E. S., Publicity Mgr., Pacific States Cast Iron Pipe Co., Provo, Utah.
Soderstrum, J. P., City Mgr., City Hall, Grand Junction, Colo.
Streeter, Robert L., Civil Engr., Gillette, Wyo.
Urquhart, M. B., 2162 Market St., Denver, Colo.
West, Paul L., City Comm., City Hall, Pueblo, Colo.
Williams, L. O., State San. Engr., State House, Cheyenne, Wyo.

Sewage Division, Texas Section, S. W. W. A.

V. M. Ehlers, *Secretary*, State Department of Health, Austin, Texas

Bantel, E. C. H., Dr., University of Texas, School of Engineering, Austin, Texas.
Becker, Philip G., Jr., 1009 Orange St., Fort Worth, Texas.
Bellamy, W. D., Dist. Sanitary Engineer, P.O. Box 301, Huntsville, Texas.
Berg, E. J. M., 236 Peck St., San Antonio, Texas.
Boaz, William, c/o State Dept. of Health, Austin, Texas.
Carr, J. Matt, San. Eng., City-County Health Dept., El Paso, Texas.
Cochran, N. E., 302 W. Ave. B, San Angelo, Texas.
Dalton, M. L., Consulting Engr., Dallas Bank and Trust Bldg., Dallas, Texas.
Dodson, Lewis, Dist. Supr., 107½ W. Fifth Ave., Amarillo, Texas.
Fowler, James D., Consulting Engr., 801 Central Bank Bldg., Dallas, Texas.
Green, T. C., Supt., City Filtration Plant, Austin, Texas.
Hallmark, G. D., City Engr., Mexia, Texas.
Haneman, Jr., A., Dist. Sanitary Engr., P.O. Box 476, Victoria, Texas.
Hardy, W. C., Dist. Supr., P.O. Box 1785, Beaumont, Texas.
Hargis, H. E., Sanitation Supra., 301 Insurance Bldg., San Antonio, Texas.
Heins, Frank C., City Engineer, Laredo, Texas.
Helland, H. R. F., Consulting Engr., Frost National Bank Bldg., San Antonio, Texas.
Johnson, Clarence W., Dist. Supr., P.O. Box 641, Houston, Texas.
Joiner, W. N., Water Works Supt., San Marcos, Texas.
Livingston, L. E., 3921 Purdue St., Dallas, Texas.
Lueders, E. T., Dist. Supr., P.O. Box 922, Kingsville, Texas.
McAfee, H. D., City San. Engr., Corsicana, Texas.
Mahlie, W. S., City Chemist, Water Filtration Plant, Fort Worth, Texas.
Moor, W. C., Chemist, Armour and Co., Stock Yards Sta., Fort Worth, Texas.
Oliver, J. C., Dist. San. Engr., Floydada, Texas.
Pearl, E. H., 1613 Sabine St., Austin, Texas.
Powell, W. J., Consulting Engr., 2022 Republic Bank Bldg., Dallas, Texas.
Richey, R. T., Health Office, District No. 5, Kingsville, Texas.
Sanders, M. K., c/o Greene Bros., 1812 Griffin St., Dallas, Texas.
Smith, M. R., Jr., City Engr., Lubbock, Texas.
Stanley, Walter S., San. Engr., City Health Dept., San Antonio, Texas.
Staples, W. D., San. Engr., Bell County Health Unit, Temple, Texas.
State Department of Health, Att: State Health Officer, Austin, Texas.

Steel, E. W., Prof. Texas. A. & M. College, College Station, Texas.
Turner, Oakes T., Dist. Sanitary Engr., c/o City Water Dept., Dallas, Texas.
Ward, Joe E., Consulting Engr., 545 Harvey-Snider Bldg., Wichita Falls, Texas.
Weiss, R. H., Dist. San. Engr., P.O. Box 173, Kerrville, Texas.
Whedbee, Edgar, Sr. Engr., City Water Dept., Dallas, Texas.
Yaffe, C. D., Supt., City Sewage Treatment Plant, El Paso, Texas.

The Canadian Institute of Sewage and Sanitation

Albert E. Berry, *Secretary-Treasurer*, Sanitary Engineering Div., Ontario Dept. of Health, Toronto, Ontario, Canada

Adams, F. P., City Engr., City Hall, Brantford, Ont., Canada.
Baird, E. M., Township Engr., 11 Avalon Blvd., Scarborough, Ontario, Canada.
Barry, David, Major, Engineer, National Defence, Canadian Bldg., Ottawa, Ontario, Canada.
Bell, W. J., Dr., President, Canadian Centrifugal Corp., 1104 Royal Bank Bldg., Toronto, Canada.
Berry, A. E., Esq., Director, Sanitary Eng. Div., Ontario Dept. of Health, 235 Gainsboro Road, Toronto, Ont., Canada.
Bieth, Robert, Mayor, Preston, Ontario, Canada.
Bowness, G. W., Gen. Mgr. Nichols Eng. and Research Corp. of Canada Ltd., University Tower Bldg., Montreal, Quebec, Canada.
Bradley, Harold D., Deputy St. Commissioner, 90 Albert St., Toronto, Ontario, Canada.
Brereton, W. P., City Engr., 223 James Ave., Winnipeg, Manitoba, Canada.
Brown, J. H., City Engr., Oshawa, Ontario, Canada.
Bryce, W. F. M., Esq. Sewer Engr., Transportation Bldg., Ottawa, Ontario, Canada.
Burnett, A. H., Supt. Union Sewerage Comm., Town Hall, Mimico, Ontario, Canada.
Casey, William, Pres., Canadian Locomotive Co., Ltd., Kingston, Ont., Canada.
Chamberlain, C. C., Esq., Supt., Township of York Disposal Plant, 530 Rushton Road, Toronto, Ontario, Canada.
Collins, W. H., Sewer Eng. City of Hamilton, 16 Senator Ave., Hamilton, Canada.
Cousineau, A., Supt. Engr. Div. of Sanitation, Dept. of Health, City Hall Annex, Montreal, P. Q., Canada.
Cyr, Rene, Esq., Asst. Sanitary Engr., c/o Provincial Bureau of Health, 89 E. Notre Dame St., Montreal, Quebec, Canada.
D'Aeth, J. B., Esq., Fraser, Brace, Ltd., 107 Craig St., Montreal, P. Q., Canada.
Darling, E. H., Esq., Consulting Engr., 513 Pigott Bldg., Hamilton, Ontario, Canada.
Durrant, W. K. F., Chief Opr., Sewage Disposal Works, P.O. Box 43, Moose Jaw, Saskatchewan, Canada.
Engineer, The, Etiobicoke Township, Islington, Ontario, Canada.
Ferguson, G. H., Esq., Chief Engr., Dept. of Pensions and National Health, Daily Bldg., Ottawa, Ontario, Canada.
Foggie, J., Chief Sanitary Inspector, Dept. of Health and Public Welfare, Legislative Bldg., Winnipeg, Canada.
Francis Hankin and Company, Ltd., 2028 Union Ave., Montreal, Canada.
Francis, H. F., Shaunavon, Saskatchewan, Canada.
Grassie, C. A., Esq., Town Engr., Port Colborne, Ontario, Canada.
Hamel, Edouard, Chief Engr., City Hall, Quebec, Canada.
Harris, R. C., Commissioner of Works, City Hall, Toronto 2, Canada.
Hobson, N. C., Bus. Mgr., Canadian Industries, Ltd., Windsor, Ont., Canada.
Howard, N. J., Director, Filtration Plant Laboratory, 410 Lake Shore Road, Centre Island, Toronto, Ontario, Canada.
Hubel, J. H., Chemical Engr., Development Department, Canadian Industries, Ltd., Montreal, Canada.
Jack, D., Asst. Engr., Dept. of National Health, 22 Bank of Nova Scotia Bldg., St. Catharines, Ontario, Canada.
Jack, Grant R., Esq., Commissioner of Works, Township of East York, 787 Coxwell Ave., Toronto, Ont., Canada.
Kingston, T. J., Township Engr., P.O. Box 535, South Porcupine, Ontario, Canada.
Kinney, J. B., Esq., Mgr., Wallace & Tiernan Co., Ltd., 345 Sorauren Ave., Toronto, Ontario, Canada.
Knight, Ray R., Toronto Mgr. Francis Hankin and Co., 165 Spadina Ave., Toronto, Ontario, Canada.
LaFreniere, Theo J., Provincial San. Engr., Bureau of Health of Quebec, 89 East Notre-Dame, Montreal, Que., Canada.

Lamson, B. F., City Engr., St. Catharines, Ont., Canada.

Laurie, Albert, Laurie and Lamb, 132 St. James St., Montreal, Quebec, Canada.

Lea, W. S., Consulting Engr., 1226 University St., Montreal, Canada.

McCannel, D. A. R., City Engr., City Hall, Regina, Sask., Canada.

McDonald, N. G., Esq., Consulting Engr., 1130 Bay St., Toronto, Ont., Canada.

McFaul, W. L., City Engr., Hamilton, Ontario, Canada.

McNiece, L. G., Esq., Town Engr., Orillia, Ontario, Canada.

MacLaren, J. F., Esq., Consulting Engr., 1130 Bay St., Toronto, Ont., Canada.

MacLaren, L. A., 31 Granville Road, Hampstead, Montreal, Canada.

MacLean, J. D., Town Engr., Box 433, Timmins, Ont., Canada.

MacNicol, N., Works Commissioner, 333 Lonsdale Road, Forest Hill, Ont., Canada.

Malcolm, Wm. L., Prof. Municipal Engineering, Queen's University, Kingston, Ont., Canada.

Marsh, H. M., Vice-Pres., W. J. Westaway Co., Ltd., Hamilton, Ont., Canada.

Menzies, D. B., Prov. San. Engr., 218 Administration Bldg., Edmonton, Alberta, Canada.

Menzies, J. Ross, 170 Place d'Youville, Montreal, Quebec, Canada.

Miller, W. C., Esq., City Engr., 24 Curtis St., St. Thomas, Ontario, Canada.

Nasmith, G. G., Dr., Consulting Engr., Gore, Nasmith & Storrie, 1130 Bay St., Toronto, Ontario, Canada.

Necker, C. E., Town Engr., Town Hall, Waterloo, Ontario, Canada.

Nicklin, H. S., Esq., City Engr., City Hall, Guelph, Ontario, Canada.

Oke, Ernest E. W., Mgr. and Engr., Public Utilities Comm., Palmerston, Ontario, Canada.

Owen, Mark B., Supt. Public Works, 7752 Kentucky Ave., Dearborn, Michigan.

Perry, A. H., Asst. Engr., P.O. Box 1012, Vancouver, B. C., Canada.

Phelps, Geo., Esq., Engineer of Sewers, Dept. of Works, City Hall, Toronto, Ontario.

Pringle, H. L., Mgr., Public Utilities Commission, Whitby, Ontario, Canada.

Redfern, W. B., Esq., Consulting Engr., Excelsior Life Bldg., 36 Toronto St., Toronto, Ont., Canada.

Riehl, W. H., Esq., City Engr., City Hall, Stratford, Ontario, Canada.

Roberton, L. T., Sewage Disposal Engr., 565 William St., London, Ont., Canada.

Roe, Frank C., San. Engr., Canadian Carborundum Co., Ltd., Niagara Falls, N. Y.

Rogers, M. W., Mgr. Public Utilities Comm., Carleton Place, Ontario, Canada.

Russell, J. P., Esq., Editor, Engineering and Contract Record, 347 Adelaide St., West, Toronto, Ontario, Canada.

Salmon, Jas. J., Esq., Pres. and Gen. Mgr., "Canadian Engineer," 341 Church St., Toronto, Ont., Canada.

Scheak, H. M., 75 Rosedale Heights, Toronto, Ont., Canada.

Shook, H. R., Esq., Asst. Sales Mgr., National Sewer Pipe Co., 44 Victoria St., Toronto, Ontario, Canada.

Shupe, S., City Engr., City Hall, Kitchener, Ontario, Canada.

Spellman, W. A., Consulting Engr., 111 Pandora Ave., Kitchener, Ontario, Canada.

Stalker, W. D., Mgr. Pub. Utilities Comm., Simcoe, Ontario, Canada.

Storrie, Wm., Esq., Consulting Engr., 1130 Bay St., Toronto, Ont., Canada.

Symes, C. B., City Engr., Fort William, Ont., Canada.

Thomas, A. H. R., Supt. Public Utilities Comm., 874 Lake Shore Road, New Toronto, Ont., Canada.

Van Benschoten, J., Esq., Mgr. Paterson Engineering Co., of Canada Ltd., 58 Pelham Ave., Toronto, Ontario, Canada.

Veitch, Wm. M., Esq., City Engr., City Hall, London, Ontario, Canada.

Watmough, W. W., Supt. Chemist., Depew Disposal Plant, 32 Myrtle Ave., Hamilton, Ont., Canada.

Wilson, G. G., Chief Opr. Ponoka Mental Hospital, P.O. Box 5, Ponoka, Alberta, Canada.

Wood, J. R., Esq., Asst. City Engr., City Hall, Calgary, Alberta, Canada.

Young, C. R., Prof., Dept. of Civil Engineering, University of Toronto, Toronto, Canada.

Argentine Society of Engineers

Hugo Albertelli, *Secretary*, Calle Espana 635, Goya (Prov. de Cerrientes), Argentina, S. A.

Acuna, Manuel, 3 de Febrero 976, Buenos Aires, S. A.

Ahumada, J. M. (hijo), Charcas 1840, Buenos Aires, S. A.

Albertelli, Hugo, Calle Espana 635, Goya (Prov. de Cerrientes), Argentina, S. A.
Artaza, Evarista, E. Costa 202, San Isidro, Buenos Aires, S. A.
Barbeito, Arturo L. Auderut, Teodoro Garcia 2483, Buenos Aires, S. A.
Berrino, Juan B., Paraguay 3690, Buenos Aires, S. A.
Bodenbender, Otto E., Paraguay 4615, Buenos Aires, S. A.
Bottaro, Juan C., Avenida Tres Cruces 4326, Buenos Aires, S. A.
Calandra, Raul A., Cangallo 2630, Buenos Aires, S. A.
Claypole, Jorge, Labarden 257, San Isidro, Buenos Aires, S. A.
Dupont, Enrique, Cangallo 1539, Buenos Aires, S. A.
Edelberg, Benjamin, Charcas 4250, Buenos Aires, S. A.
Figini, Angel, Avda. Roque Saenz Pena 501, Buenos Aires, S. A.
Gerardi, Donato, Calle 50 N° 789, LaPlata, Buenos Aires, S. A.
Lagos, Alberto A., Zabala 2630, Buenos Aires, S. A.
Lopez, Ing. Jose, Paez 2445, Buenos Aires, Argentina, S. A.
Luppi, Ricardo, Treinta y tres 167, Buenos Aires, S. A.
Perazzo, Roberto J., Potosi 4056, Buenos Aires, S. A.
Repetto, Blas A., Guatamala 4429, Buenos Aires, S. A.
Sanazar, Mirza, Calle Cordoba 1336, Buenos Aires, S. A.
Sarmiento, Pedro Pascual, Olleros 2105, Buenos Aires, S. A.
Semino, Carlos L., Yerbal 1142, Buenos Aires, S. A.
Sierra, Gabino A., Pasage La Rural 161, Buenos Aires, S. A.
Trelles, Rogelio A., Charcas 2380, Buenos Aires, S. A.

The Institute of Sewage Purification—England

J. H. Garner, *Secretary*, 28 Aberford Road, Wakefield, Yorks., England

Artist, L. J., 8, Welbeck St., Wakefield, England.
Arrowsmith, E. H., Sewage Works, Lower Bredbury, Nr. Stockport, England.
Balfour, D. Ross, 47 Victoria St., Westminster, London S.W. 1, England.
Barker, A., Bankside, Greenfield, Nr. Oldham, England.
Barraclough, D. H., North Bierley Sewage Works, Oakenshaw, Bradford, England.
Bell, H. D., Sewage Works, Burton Grange, Barnsley, England.
Betts, D. M., "Berl House," Thynne Road, Billericay, Essex, England.
Birkett, E. B., The Lodge, Southern Sewage Works, Ealing, London, W. 5, England.
Bolton, J., Sewage Works, Bury, Lancs., England.
Bolton, J. F., Ames Crosta Mills and Co., Ltd., Moss Iron Works, Heywood, Lancs., England.
Boothman, J., Sewage Works, Coppy Clough Church, Accrington, Lancs., England.
Brown, J. R., Sewage Works, Dowley Gap, Bingley, Yorkshire, England.
Calvert, A., 43 Station Road, Darnall, Sheffield, England.
Campbell, J. L., Manor Farm Sewage Works, Reading, Berkshire, England.
Chadwick, A. R., Sewage Works, Marley, Keighley, England.
Christian, J. A., Gorse Lane, Anstey, Leicester, England.
Clay, H., Dr., 175 Radcliffe Road, Milnsbridge, Huddersfield, England.
Collins, S. T., Sewage Works, Dewsbury Road, Churwell Nr. Leeds, England.
Craig, J., Bretons Farm, South Hornchurch, Essex, England.
Crowther, J. W., 19 Cliff Road, Darfield Nr. Barnsley, England.
Degg, A., 1 Sandbeck Ave., Skegness, Lincolnshire, England.
Duxbury, S., Bungalow, Summerhouse Hill, Cardington, Beds., England.
Edmondson, J. H., Sewage Works, Wincobank, Sheffield, England.
Ellerey, H. G., South Farm, Langton Green, Tunbridge Wells, Kent, England.
Evans, J. E., Bankhall Lane, Hale, Cheshire, England.
Evans, S. C., Sewage Works, Byegrove Road, Merton, England.
Fidler, G. C., 122 Standen Road, Wincobank, Sheffield, England.
Fowler, G., Brighouse Sewage Works, Cooper Bridge, Mirfield, Yorkshire, England.
Gambrell, H. S., 35 Kent St., Whitstable, Kent, England.
Garner, J. H., Brynfield, 28 Aberford Road, Wakefield, Yorkshire, England.

Gillard, J. E., Sewage Works, Leamington, Warwickshire, England.
Goldthorpe, H. H., Shelley, Huddersfield, England.
Gough, T., Sewage Works, The Bottoms, Heckmondwike, Yorkshire, England.
Graham, J. A., Sewage Works, Naburn, York, England.
Hall, R., Perry Oaks Disposal Works, Tithe Barn Lane, West Drayton, Middlesex, England.
Halliwell, E., 2 Stanley Place, Preston, Lancs., England.
Hambleton, F. T., Outfall Works, Prestbury Nr. Macclesfield, England.
Hamlin, C. H., Sewage Works, Windmill Road, Luton, Beds., England.
Hammerton, C. H., The Purification Works, Gabel-al-Asfar, nr. Cairo, Egypt.
Harvey, J. B., Rochester and Chatham Joint Sewage Board, Rainham, Kent, England.
Hicks, R., Gravesend Sewage Works, Denton, nr. Gravesend, Kent, England.
Hillier, W. H., Chief Engineer's Dept., London County Council, County Hall, London S.E. 1, England.
Hodgson, E., Irrigation Farm, Harrington Road, S. Norwood, London S.E., England.
Hodgson, H. J. N., 22 Brae Road, Glenelg Gardens, South Australia.
Holroyd, A., Chemist, Dagenham Urban District Council, Riverside Sewage Work, Rainham, Essex, England.
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Howarth, J. P., Sewage Disposal Works, Longford Road, Cannock, Staffs., England.
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Solvay and Co., 33, Rue Prince Albert, Att: Section E, Bruxelles, Belgium.

British West Indies

Chief Engineer, The Water Commission, Kingston, Jamaica, B. W. I.

Canada

Dorr Company, 602 Victory Bldg., Toronto, Ont., Canada.

Ecole Polytechnique, 1430 St. Denis St., Montreal, Canada.

Haddon, A. M., City Engineer, Engineering Dept., 608 Civic Block, Edmonton, Alberta, Canada.

Howard, N. J., Director, Filtration Plant Laboratory, 410 Lake Shore Rd., Centre Island, Toronto, Ontario, Canada.

McGill University Library, 3459 McTavish St., Montreal, Quebec, Canada.

McLean, D. L., 701 McMillan Ave., Winnipeg, Canada.

Provincial Bureau of Health, 89 Notre-Dame St., East, Montreal, Quebec, Canada.

Queen's University Library, The Douglas Library, Kingston, Ontario, Canada.

University of Saskatchewan, The Library, Saskatoon, Saskatchewan, Canada.

University of Toronto, Library, Toronto 5, Canada.

China

Alma, J. F. M., Esq., Public Works Dept. of Nanking, Section for Sewerage and Drainage, Municipality of Nanking, Nanking, China.

Chief Sanitation Chemist, The, Shanghai Municipal Council, Shanghai, China.

Chihobu Kojika, South Manchuria Railway Co., Dairen, Manchuria, China.

Koo, T. Y., Sanitary Engineering Dept., National Health Administration, Nanking, China.

Oriental Book Store, The, 164 Victoria Road, Tientsin, North China.

Tao, P. K., Prof., Dept. of Sanitary Engineering, National Health Administration, Nanking, China.

Tsing Hua University Library, Peiping, China.

Wang, T. T., Dept. of Sanitary Engineering, National Health Administration, Nanking, China.

Whampoa Port Development Admin., The, Ching Nam Road, Canton, China.

Czechoslovakia

Calve'sche Buchhandlung, J. G., Robert Leiche, Prag, Czechoslovakia.

Cikan, F., Vaclavska ulie 35/III, Prague II, Czechoslovakia.

Ignatz Spiro & Sonne, A. G., Cesky Krumlov, Czechoslovakia.

Topic, F., 11, Narodni, Prague, Czechoslovakia.

Denmark

Gad's Boghandel, G. E. C., Vimmelkaftet 32, Copenhagen, Denmark.

Joergensen, Arthur, Norregade 20, Copenhagen K, Denmark.

Larsen Boghandel & Papirhandel, Vilhelm, Jernbanegade 2, Odense, Denmark.

Dutch East Indies

Geneeskundig Laboratorium, Afdeeling Bibiliotheek, Oranje Boulevard, 79 Batavia Centrum, Dutch East Indies.

England

Abbott, W., Ltd., 32 Eastcheap, London, E.C. 3, England.

Activated Sludge, Ltd., 100 Victoria St., Westminster, London, S.W. 1, England.

Adams-Hydraulics Limited, Peaseholme Green, York, England.

Bennett, Mr. W., Birmingham Tame and Rhes Drainage Board, Rookery Park, Erdington, Birmingham, England.

Castner-Kellner Alkali Co., Ltd., Weston Point, Runcorn, Cheshire, England.

Director of Publications, Books Section, His Majesty's Stationery Office, Princes St., Westminster, S.W. 1, England.

Dorr-Oliver-Ltd., Abford House, Wilton Road (Victoria), London, S.W. 1, England.

Engineer in Charge, The, West Middlesex Main Drainage Works, Oak Lane, Isleworth, Middlesex, England.

Farrer, Messrs. Wm. E., Ltd., Star Works, Health Mill Lane, Birmingham, 9, England.

Forbes, Ian Campbell, 131 Castle Road, Castle Gresley, Burton-on-Trent, Staffordshire, England.

General Chemicals, Ltd., Messrs. I. C. I., Records Dept., Cunard Bldg., Liverpool, England.

Harwood, F., 24, Box Ridge Ave., Purley, Surrey, England.

Manchester Corp. Rivers Dept., Att: Mr. W. Porthouse, Secy., 89 Oxford St., Manchester, England.

Medical Officer of Health, 328, The County Hall, London, S.E. 1, England.

Patent Office Library, The Librarian, 25, Southampton Bldgs., Chancery Lane, London, W.C. 2, England.

Peter Spence and Sons, Ltd., Farnworth nr. Widnes, England.

Player, R. C., c/o Messrs. Lemon and Blizard, Chartered Civil Engineers, Castle Lane, Southampton, England.

Porteous and Company, W. K., Abbey House, Victoria St., Westminster, London, S.W. 1, England.

Unifloc Reagents Limited, 10 Adelaide St., Swansea, Great Britain.

Wolstenholme and Son, Ltd., John, Radcliffe, Lancashire, England.

Finland

Helsingin kaupungin Rakennustoimisto, Katurakennusosasto, Kasarminkatu 21, Helsinki, Finland.

France

Bibliotheque de l'Institute Pasteur, 20, Boulevard Louis XIV, Lille (Nord), France.

Guilbert, Monsieur J., Director, Etablissements Luchaire, 171 Boulevard Haussmann, Paris, 8°, France.

Monsieur le Directeur General des Travaut, 98 Quai de la Rapee, Paris, France.

Omnium d'Assainissement, 20 Rue d'Athenes, Paris, 9e, France.

Societe Generale d'Epuration et d'Assainissement, 28 Rue de Chateaudun, Att: Le Directeur, Paris, France.

Germany

Bach, Herman, Dr., Barbarossastr. 52 I, Berlin, W. 30, Germany.

Bibliothek der Technischen Hochschule. Berlinerstr. 171–172 Berlin-Charlottenburg 2, Germany.

Chlorator-G. m. b. H., Alexandrinenstr. 48, Berlin, S.W. 19, Germany.

Conrad Behre, Uberseeische Buchhandlung, Dornbusch 12, Hamburg 1, Germany.

Dahlem, Hans, Schnutenhasstr. 63, Essen-Sud, Germany.

Deutsche Chemische Gesellschaft, Sigismundstrasse 4, Berlin, W. 35, Germany.

Emschergenossenschaft, Postfach 219, Kronprinzenstrasse, No. 24, Essen, Germany.
Farbenindustrie Aktiengesellschaft, I. G., Zentral-Finanzverwaltung, Unter den Linden 78, Berlin, N.W. 7, Germany.
Fries, Franz, Ober-Ingenieur. Kronprinzenstr. 37, Essen-Ruhr, Germany.
Hirschwaldsche Buchhandlung, Unter den Linden 60, Berlin, N.W. 7, Germany.
Imhoff, Dr. Karl, Hauptpostgebaude, Essen, Germany.
Kehr, Ing., Dr., Technische Hochschule Hannover, Lehrstuhl fur Wasserwirtschaft, Hannover, Germany.
Lerner, Hermann, 10 Futterstrasse, Wuppertal-Barmen, Germany.
Mahr, Dr. Ing., Wupperverband, Wuppertal-Barmen, Emilienstr. 11, Wuppertal, Germany.
Merkel, W., Dr., Julius St. 5, Wiesbaden, Germany.
Muhlau, Walter G., Buchhandlung, Brunswiker Strasse 29a, Kiel, Germany.
Niersverband, Postschliessfach 91, Viersen, Germany.
Preussischen Landesanstalt fur Wasser, Boden und Lufthygiene, Wassermannplatz 1, Berlin-Dahlem, Germany.
Pruss, Max Dr., Ruhrverband, Kronprinzenstrasse 37, Essen, Germany.
Rohde, Herbert, Dr., Ing., Ruhrverband, Kronprinzenstrasse 37, Essen, Germany.
Ruhrverband, Kronprinzenstr. 37, Essen, Germany.
Sierp, Dr. F., Eichbenstr. 70, Essen-Staatwald, Germany.
Stadt. Chem. Untersuchungsamt, Forststr. 18, Stuttgart, Germany.
Viehl, K., Dr., Krosigstr. 9, Leipzig, N. 22, Germany.
Wittwer, Konrad, Schlosstrasse 14, Stuttgart, Germany.
Zeitungen fur Postamt, Weisbaden 1, Germany.
Zeitungen fur Postamt, Nuerrberg 2, Zeitungszustellung, Germany.

Holland

Dorr-Oliver-N. V., P.O. Box 59, The Hague, Holland.
Kirberger & Kesper, Ltd., 153 Rokin and 1 Doelenstraat, Amsterdam, Holland.
Meulenhoff & Co., Amsterdam, Holland.
Oostwoud Wijdenes, Ir. J. M. J. W., Alberdingk Thijmlaan 4, Bussum, Holland.
Post Office, La Hague, Holland.
Van Wezel, M., Lubeckstraat 21, The Hague, Holland.
Zee, H. v. d., Dr., Roerstraat 76, Amsterdam (Z), Holland.

Hungary

Kozponti Csatorna es Szivattyutelep, Goroksari ut 31, Budapest IX, Hungary.

India

Chief Engineer, The, Public Health Dept. Engineering Branch, 3 Charnock Place, Calcutta, India.
Divisional Engineer, The Maintenance Division, Drainage Department, Hyderbad-Deccan, India.
King Institute, Director, Guindy, Saidapet P.O., Madras, India.
Smehtr, R., State Engineer, Drainage Section, Bhavnagar, P. W. D., India.

Ireland

The Library, Periodical Dept., University College, Cork, Ireland.
Herlihy, D. F., 6 Rosmeen Gardens, Dun Laoghaire Co., Dublin, Ireland.

Italy

Acquedotto Pugliese, Bari, Italy.
DeGiorgi & K. Mengis, Ingg. U. A., Via Antonio Canova 27, Milano (126), Italy.
Dorr-Oliver, S. A. I., Corso del Littorio 3, Milano, Italy.
Istituto di Igiene of the R. Universita, Via Alfani 33, Florence, Italy.
Morgenroth, F., Dipl.-Ing., Viale Druso 51, Bolzano, Italy.
Rosenberg, E. Romano Sig., Via Mezzocannone, 31, Naples 70, Italy.
Societa Italiana per Acquedotti e Fognature, Via Clerici No. 2, Milano, Italy.

Japan

"Doboku" Engineering College, Kyushu Imperial University, Fukuoka, Japan.
"Gesui-ka," c/o Maruzen Co., Ltd., Branch Office, Sanjodori, Kyoto, Japan.
Furitsu Ikadaigaku, Chuotoshokan, Kawaramachi Hirokoji, Kyoto, Japan.
Hirose, K., Prof., Dr., c/o Institute of Civil Engineering (Doboku-kyoshitsu), Faculty of Engineering, Tokyo Imperial University, Hongo, Tokyo, Japan.
Ito, Sumio, 9, Komatsu-cho 1-chome, Higashiku, Nagoya, Japan.
Matsumaru, Isao, 299 Katayama Chisato-mura, Mishimagun near Osaka, Japan.
Nagai, Toyotaro, Osaka Shiritsu Eisei Shikensho, Kita-Ogimachi, Kitaku, Osaka, Japan.

Naruse, Kaoru, c/o Nagoya-Shiyakusho, "Suido-bu," Ohtsu-machi, Higashiku, Nagoya, Japan.
Niigata-Ika-Daigaku-Toshokan (Niigata Medical College Library), Niigata, Japan.
Nishihara, S., 12-1-chome, Tamachi, Shibaku, Tokyo, Japan.
Sawatake, Keizo, c/o Nagoya-Shiyakusho, "Suidobu-Gesuika," Nagoya, Japan.
Shibata, Saburo, c/o Mikawashima-Osui-Shobunjo, Mikawashima-Machi, Arakawa-Ku, Tokyo, Japan.
Suidobu, O. S., The, c/o Maruzen Co., Osaka Branch, Bakuromachi, Osaka, Japan.
Suidobu Shomuka, The, c/o Maruzen Co., Kobe Branch, Akashimachi, Kobe, Japan.
Tanaka, Akira, No. 301 Asagaya 3-Chome, Suginami-ku, Tokyo, Japan.
Tokyoshi-Suidoo-Kyoku (Gesuika) (Tokyo City Office), Marunouchi, Tokyo, Japan.
Tomita, Keizo, c/o Noda Shobunjo, Toyohashi, Shi, Japan.
Tsuji, Totaro, c/o Shiritsu Eisei Shikenjo, Kita Ogimachi Kitaku, Osaka, Japan.
Yokohama Water Works Office, Yokohama City Office, Yokohama, Japan.
Yonemoto, S., Cons. Engineer of the Public Works Bureau of Home Dept., 98 1-chome, Sugamo-machi, Tokyo, Japan.

Mexico

Villa-Acosta, Alfonso, Calle de la Rose 213, Mexico, D. F.

New Zealand

Under-Secretary, The, Department of Internal Affairs, Wellington, New Zealand.

Palestine

Palestine Water Company, Ltd., The, P.O. Box 76, Jerusalem, Palestine—Att: Mr. I. Vilentchuk.
Porteous, Norman, Office of the Engineer in Charge, Haifa Main Drainage, Haifa, Palestine.

Poland

Centrale des Journaux Etrangers, rue Krak-Przedm. 17, Warsaw, Poland.
Katedra Budownictwa Wodnego I, Politechniki Warszawskiej, ul. Polna 3, Warsaw, Poland.
Sewage Experimental Station, Marymoncka 16, Warsaw, Poland.

Portugal

Garcia, Raul Ressano, R. dos Navegantes 65, Cascaes, Portugal.
Prazeres, Agnelo C., 14-R. Joaquim Bonifacio, Lisbon, Portugal.

Roumania

Institutul di Igiena si Igiena Sociala, The, Universitatea din Cluj, Cluj, Roumania.

Russia

Below, P. S., Prof., Nowaja Basmannaja, I-y Basmanniy per. 12, kw. 15, Moscow, U. S. S. R.
Bezuner, I. S., Gogolewskaja 44, KW 25, Tula, U. S. S. R.
Bibliogr. Sektoru Gosud. Nautschn. Bib-ki NKTP, Nal. Bronnaja 4, Moskwa, 104, U. S. S. R.
Biblioteke Akademii, Kommunaljn. Khoz-Va, Gl. Pochtamt, Pocht. Jaschik 939, Moscow, U. S. S. R.
Gorjkowskij Institut, Sanitarii I Gigieni, Ul Semaschko D. 18, Gorjkij, U. S. S. R.
Institutu Kommunalijnoj Gigieni, Puschkinskaja 14, Charkow, U. S. S. R.
Institute of Sanitation and Hygiene, Pogodinskaya No. 10, Moscow, U. S. S. R.
Kraevoj Dom Sovetov, 2 Kor. 3 et. Kom. 88–89, Rostow N/D, U. S. S. R.
Kuibischewsk Stroiteljn. In-tuim Mikojana A. I., Kooperatiwnaja 194, Kuibischeu, U. S. S. R.
Leningradsk. Institut, Kommunaln. Khozjajstva, Biblioteke, Prospekt Volodarskogo 22, Leningrad, U. S. S. R.
Mosk. In-t Inzhen. Kommunaljn, Stroiteljstwa, Tverskoj-Jamskoj per 17, Moskwa, U. S. S. R.
Narkomchos RSFSR INO Komn. 74, Ul. Rasina 7, Moskwa, U. S. S. R.
Nauchino-Issledovat, Institut Gidrotekhnich, Sooruzh, Ui. 3 Ijulja 50B, Leningrad, U. S. S. R.
Nautschn. Tekhn. Bibke., Uralvagonzavoda, Uralvagonzavod, Nizhnij Tagil, U. S. S. R.
Nautshnoi Biblioteke, Narkomtiashproma, Delovoi Dvor IV Podiesd, Moscow, U. S. S. R.
N. Tech. Bib-ka im. Suchomlina, Gosprom, 4 pod'esd 5 et, Charkow, U. S. S. R.
Stroit. Institutu, Institutskaja ul 4, Odessa, U. S. S. R.
Techn. Bib-Ka Wodgeo, B. Kotschki 17a, Moskwa, U. S. S. R.
Trest Sojuswodstroj, Pokrowka 37, Moskwa, U. S. S. R.

Trestu "Kommunstroi," Rybnyj per 3, Moskwa Centr., U. S. S. R.

Trestu "Mosotschistwod," Teatraljnij proesd. d3, pod. 4-j, etash 4-j, Moskwa, U. S. S. R.

Wodokanalproekt. Schabolowka, 4-j Werchne-Michajlowskij pr. 8, Moskwa, U. S. S. R.

Scotland

Babtie, Shaw and Morton, 17 Blythswood Square, Glasgow, C. 2, Scotland.

Glasgow Corporation, City Analysis Dept., 20 Trongate, Glasgow, Scotland.

Knox, J., Esq., Drainage Engineers Office, 23, Clydesdale St., Hamilton, Lanarkshire, Scotland.

Stephen, F. M., Esq., County Drainage Engr., 23, Clydesdale St., Hamilton, Lanarkshire, Scotland.

Thomson, Esq., A. L., Sewage Works Manager, High Road, Motherwell, Lanarkshire, Scotland.

South America

Aguirre, Eduardo Ing., Jefe., Departamento de Hidraulica, Direccion de Obras, Publicas, Santiago, Chile, S. A.

Altoberro, J. C., 2029 Charrua St., Montevideo, Uruguay, S. A.

Biblioteca de Facultad de Ingenieria, Cerrito 73, Montevideo, Uruguay, S. A.

Direccion General de Alcantarillado de Santiago, Casilla 577, Santiago, de Chile, S. A.

Direccion general del Agua Potable y Alcantarillado, Casilla 24-D, Santiago de Chile, S. A.

Direccion General of Aprovisionamiento Del Estado, State Gen. Supply Dept., General Management of Drinking Water and Sewerage Item 4504, Santiago, Chile, S. A.

Gianoni, Adam, 2434 Agraciada St., Montevideo, Uruguay, S. A.

Gomez, E., Diagonal Norte 567, Buenos Aires, Argentina, S. A.

Netto, J. P. De Lemos, Caixa Postal 3244, Rio de Janeiro, Brazil, S. A.

Ortiz, Pedro C., Calle 18-A, No. 1–75, Bogota, Colombia, S. A.

Petre, Ing. Martin F., Balcarce 251, Jujuy, Argentina, S. A.

Rio de Janeiro City Improvements Co., The, 69 Santa Luzia, Caixa 403, Rio de Janeiro, Brazil, S. A.

Straits Settlements

Municipal Engineer, The, Municipal Offices, Sewerage Department, Singapore, S. S.

Sweden

A. B. Gleerupska Univ. Bokhandeln, Lund, Sweden.

Kgl. Tekniska, Hoegskolans, Bibliotek Valhallavaegen, Stockholm, Sweden.

Nordiska Bokhandeln, A. B., Drottninggatan 7, Stockholm, Sweden.

Vattenbyggndasbyran, A. B., Humlegarsgatan 29, Stockholm, Sweden.

Switzerland

Versuchsanstalt f. Wasserbau, E. T. H., Beratungsstelle f. Abwasserreingigung and Trinkwasserversorgung, Gloriastrasse 37, Zurich 7, Switzerland.

Waser, E., Prof. Dr., Kantonschemiker, 15 Fehrenstrasse, Zurich 7, Switzerland.

Turkey

Robert College, Library, Bebek, Istabul, Turkey.

Yugoslavia

St. Kugli (L. Hartman), Ilica 30, Zagreb, Yugoslavia.